Introduction

I never think of the future—it comes soon enough.

Albert Einstein

Chapter 1

Threads

Fundamentals of Nanotechnology is about technology—the manufacturing of high-tech (and not so high-tech) goods. It is about converting nanoscience into products. It is not so much about science although we do not refrain from relating to scientific principles, concepts. Our focus is on topics associated with materials, manufacturing (fabrication), devices, and applications. It is, in every way, a complement to *Introduction to Nanoscience*, a text that focuses primarily, as the title suggests, on the science and not on the technology. The format of the text is that of a cooperative, interdisciplinary effort that is typical of nano—albeit with emphasis on engineering—where biology, chemistry, and physics (and computer science) come together to contribute to this very broad subject.

The chapter opens with a short course on how to start, maintain, and exit a business. Although it applies to nearly any kind of business, it most certainly applies to nanobusiness. This is an unprecedented approach, to include such a topic in a technology textbook, but it has to be done in order to keep pace with our changing world. We accomplish our due diligence by offering this material in this chapter as well as a section on education and workforce development. It is one thing to understand the technology and pass the course with flying colors; it is quite another thing to know what to do with it or plan a career centered on its impact.

Nanometrology, nanomanufacturing, and research have to be conducted somewhere. Where they take place is actually quite important. As one might gather from the prefix, nano implies things that are very small, and being small, working with nanomaterials, measuring them, and making them all require special facilities and considerations. We discuss nanometrology and nanomanufacturing in *chapter 2* but we also turn our attention to the buildings that house them—the buildings for advanced technology. This is a rather unusual section in that material of this ilk is not usually found in science and engineering texts—but we have already broken that rule by adding a short course in business development and operation. However, by understanding what it takes to make nano happen, the student should acquire an even broader appreciation of the subject matter—and perhaps interest in a career path along the lines of architecture and engineering buildings for advanced technology may just be a beneficial byproduct of this chapter.

Lastly, we provide a catalog of nanotechnology institutions and products. We highly recommend that you visit some of the Web site links provided so that a broader perspective of nanotechnology can be acquired. Following this chapter, a special chapter on nanometrology is presented.

1.0 Perspectives of Nanotechnology

We start this adventure in 1959, at the onset of the modern age of nanotechnology, with Richard Feynman's lecture "There's Plenty of Room at the Bottom." It was in this lecture that Feynman alerted the consciousness of the scientific community about the untapped potential of nanomaterials. In *Introduction to Nanoscience*, we discussed the important historical contributions to nanotechnology and the remarkable observations of nature, wittingly or unwittingly, that were made throughout the ages and the scientific aspects of nano. We now strive to maintain focus on applications, integrated structures, and devices. However, before we embark, a small amount of reorientation is required. We start by recycling a few core definitions.

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1.0.1 Review of Definitions

In 2003, Dr. Rachel Brazil of the Royal Society of Chemistry stated quite succinctly her definition of a powerful but relatively nonspecific term—*nanotechnology* [1].

> At present, the term is used to encompass a wide spectrum of nanoscience, from nanoparticles in sunscreen to the production of 'nanobots' for in vivo medical applications. In defining nanotechnology, distinctions need to be made between 'science' and 'technology'. A narrower definition of the type of 'technology' covered by the term may also be considered, limiting nanotechnology to technology producing functional devices fabricated and operating on the scale of nanometres.

The National Science and Technology Council, Committee on Technology, Subcommittee on Nanoscale Science, Engineering, and Technology (NSET) formally established the following boundaries of nanotechnology in the year 2000 [2].

> Research and technology development at the atomic, molecular or macromolecular levels, in the length scale of approximately 1–100 nanometer range, to provide a fundamental understanding of phenomena and materials at the nanoscale and to create and use structures, devices and systems that have novel properties and functions because of their small and/or intermediate size. The novel and differentiating properties and functions are developed at a critical length scale of matter typically under 100 nm. Nanotechnology research and development includes manipulation under control of the nanoscale structures and their integration into larger material components, systems and architectures. Within these larger scale assemblies, the control and construction of their structures and components remains at the nanometer scale. In some particular cases, the critical length scale for novel properties and phenomena may be under 1 nm (e.g., manipulation of atoms at ~0.1 nm) or be larger than 100 nm (e.g., nanoparticle reinforced polymers have the unique feature at ~200–300 nm as a function of the local bridges or bonds between the nano particles and the polymer).

It is always a difficult matter to draw a hard line but one has to be drawn so that we can obtain the proper perspective and orientation. It also helps us navigate in the real world, specifically if funding and contractual issues are at stake. Let's move on and introduce (or reintroduce) the fundamental and defining characteristics of words and phrases that include the prefix *nano*.

In order to provide the necessary perspective, the following working definitions of nanotechnology, and its distinction from nanoscience, are listed below [3].

Nanoscale

The nanoscale, based on the nanometer (nm) or one-billionth of a meter, exists specifically between 1 and 100 nm. In the general sense, materials with at least one dimension below one micron but greater than one nanometer can be considered as nanoscale materials.

Nanoscience

Nanoscience is the study of nanoscale materials—materials that exhibit remarkable properties, functionality, and phenomena due to the influence of small dimensions.

Nanoscience is similar to materials science in that it is an integrated convergence of academic disciplines. There exist a couple of major distinctions between the two: size and biology. The size we understand by now but we also understand that materials science traditionally does not include biological topics.

Nanotechnology

Nanotechnology, based on the manipulation, control, and integration of atoms and molecules to form materials, structures, components, devices, and systems at the nanoscale, is the application of nanoscience, especially to industrial and commercial objectives.

Nanotechnology is a horizontal enabling convergent technology that cuts across all vertical industrial sectors while nanoscience is a horizontal integrating interdisciplinary science that cuts across all vertical science and engineering disciplines.

Nanotechnology is a disruptive technology with a high barrier of entry that will impact the development of enhanced materials and devices. Nanotechnology will require that a new genre of partnerships be formed among and between business, academe, and government. It will focus study and effort on potential societal implications of a new and certainly disruptive technology. Nanotechnology is predicted to significantly impact the wealth and security of nations. Nanotechnology is the next industrial revolution.

Nanotechnology is considered to be, more so than ever, a technology that will have great impact on all aspects of culture and society.

Nanotechnology is the application of nanoscience—plain and simple. You will see many different forms of the above definitions in the media and scientific literature, but essentially all the definitions, after distillation and purification, crystallize into a few key forms—in particular that nanotechnology consists of materials with small dimensions, remarkable properties, and great potential.

1.0.2 Technology Revolution or Evolution?

Technology (from the Greek *teknikos* meaning "art, artifice; to weave, build, join" and *tekton* meaning "carpenter") has played a major role in the history of civilization. There is not much question that technology is one of the pillars (and drivers) of civilization. After all, isn't it new technology that offers the developers of that technology an advantage in the game of life (survival)? However, a revolution implies rapid and dramatic change. What exactly are those technological advances that changed our civilization and in such a so-called revolutionary manner?

From agriculture, the *practice* of growing and harvesting food, sprung civilization. Indeed, one must agree that this is true. Early human lifestyle was altered forever as nomadic ways adapted by the hunter–gatherer gave way to the sedentary form of the farmer—truly a revolutionary change. However the processes of agriculture and irrigation were deliberately developed over an extended period of time—perhaps several thousand years. Innovations in agriculture continue as we speak—genetically modified organisms (GMOs) provide an excellent example of our high-tech foray into that arena. Although change in agricultural technology progressed quite slowly, even the gradual development of agriculture must be considered to be a revolutionary one based on its impact on civilization.

Other technological breakthroughs such as the advent of metal tools, implements, and weapons and the discovery of fire may have occurred rather spontaneously, for example, by accidental discovery (as in the case of fullerenes). These revolutionary breakthroughs are based on the discovery of a specific *type of material*—stone, copper, bronze, or iron. We can only speculate that the spread of these technologies, however, still proceeded rather slowly. There was no rapid-fire means of disseminating information (perhaps only by conquest) due to limitations in population and communication several millennia ago. Today no such barriers exist. High population density is a worldwide phenomenon, and information is spread globally in the blink of an eye. Revolutions can now be very fast. The *Industrial Revolution* of the 1800s ushered in the modern technological era. The emerging availability of hydrocarbon fuels in particular launched mechanization, mass production, transportation, and communication to levels never seen before. The telephone, television, computer, cell phone, and Internet have all changed our lives forever.

How does one then superimpose a scale of measure on a technological revolution? And what kinds of scales are relevant to nanotechnology? Revolutionary developments are measured in terms of speed, population, and impact (economic and cultural) or by weighing the overall flow of resources (in and out). For example, what percentage of a population is engaged directly in a technological revolution? "Engaged" in this case indicates the number of people working in the field, so to speak. With regard to agriculture, the percentage of population engaged in the field early on was quite low. As the practice spread over several thousands of years, greater than 90% of a population may have been rooted in the agrarian lifestyle, for example, in the Middle Ages. The pure technology sectors (R&D and manufacturing) of today may employ fewer that 10% of the total workforce but the impact (in terms of sales, use, and lifestyle) is quite enormous.

And what of nanotechnology? Is it really a revolution or is it just a natural progression in miniaturization? The advent of the transistor, integrated circuits, and the computer age certainly changed the way we accomplish our daily tasks. The *Biotechnological Revolution* added biological materials into the mix. The *Nanotechnology Revolution* is right on the back of this "revolution" inspired by biology. Many consider biotechnology to be a component of nanotechnology. All these pseudo-issues boil down to semantics and boundaries. We already have stated our opinion on boundaries. Within a generalized field such as nanotechnology that is highly interdisciplinary in nature, boundaries are consequently trampled and blurred—to a great extent.

Nanotechnology is expected to change the way we live. In that sense, it can be considered to be revolutionary. Nanotechnology is also the product of the natural evolutionary process of miniaturization. It is actually with the perception of nanotechnology (hype or not) that many are concerned. However, we should not belabor what is in essence a pseudo-dilemma—whether or not nanotechnology is the *Next Industrial Revolution*. Let's leave that discussion to the pundits, the politicians, and the omnipresent media. Rather, we should simply try and understand why these materials have remarkable properties—and within the context of this text, how nanomaterials are converted and integrated into applications. In this volume of course, we stress the applications of nanotechnology products and those enhanced (enabled) by nanotechnology. It is somewhat artificial to designate a technology to be revolutionary *before* it has run its course. **Table 1.1** outlines some of the salient features of a revolution.

TABLE 1.1 *The* Next Industrial Revolution *Compliance Check List*

Criterion	Yes	No	Comments
Basis	X		Nanotechnology is firmly grounded in reality—the physical properties and phenomena associated with nanotechnology are real and significant—they are the drivers behind the "revolution."
Speed	X		Although speed is not the only major component of a revolution, the faster it happens, the more revolutionary is its impact and the more profound its legacy. Nanotech has hit the mainstream since the mid-1990s—not that long ago. Changes nowadays are expected to occur quickly.
Track record		X	Outside of computers, pharmaceuticals, and nanoparticles, the glamorous and highly touted quantum-dots, carbon nanotubes, and drug delivery nanomaterials have not yet made a significant impact on the economy but are making headway as we speak.
Research papers, conferences	X		The scientific community has fully embraced nanoscience and nanotechnology. There is no single scientific conference in physics, chemistry, engineering, biology or medicine that does not have presentations, posters, sessions or the whole conference dedicated to nano.
Nanocompanies	X		There are more and more nanocompanies every year. Small Times Magazine lists 3500 nanocompanies just in the United States [4]. Nearly all Fortune 500 companies have some involvement in nanotechnology.
Patents	X		The number of patents (and the trend) is burgeoning—if anything, this trend indicates revolutionary proportions.
Stock market		X	Not big yet.
Institutions	X		About 500 institutions ranging from nonprofits, industry associations, research labs, economic development organizations, and university and educational institutions are registered with Small Times Magazine as nano groups [4].
% Workforce		X	Technology workforce contributes less than 10% of the total U.S. workforce in general. Nanotechnology, in its broadest sense (computers, pharmaceuticals, etc.), is already involved in many sectors. By 2015, 2 million more "nanotech" jobs are expected to emerge.
Education		X	Concerted efforts are underway to promote nanotechnology in K-12 and higher. Although a great proportion of the U.S. population knows about nanotechnology through movies, it is not considered to be a significant part of curricula at this time, but this too is changing.
Products	X	X	Nanosized transistors are already part of computer chips—although developed rather quietly without much fanfare via the natural evolutionary process of miniaturization. There is no doubt that more products will undergo enabling/enhancement from nanotechnology.
Evolutionary component		X	Evolutionary components are not considered to be revolutionary. In this case, nano is very evolutionary—emerging from micro- and biotech industries—a natural, nonrevolutionary process of miniaturization, ever since the first timepiece was developed.
Hype	X		Since the days of the "turbo," nothing has been hyped more than nanotechnology.
Upside	X		The reality-based upside and promise of nanotechnology is tremendous.

1.0.3 Outlook

What Is the Status Quo of Nanotechnology in the United States? Zyvex Labs, LLC, has recently spun out nanotube composites that are integrated into baseball bats, golf clubs, sailboat masts, ballistic armor, and radiation shielding [4]. The energy industry in collaboration with universities has developed new solar cells and new high-performance batteries. The medical industry in collaboration with universities has developed dendrimer-based viricides and advanced diagnostic instrumentation [4]. According to Jim Von Ehr, II (CEO of Zyvex), societal impacts need to be studied and carefully weighed before the release of products containing nanomaterials and devices. Encounters with luddites, nano-pretenders, and obstructionists must be sifted from those with legitimate environmental understanding and legitimate health and safety concerns. The U.S. government in the form of the National Nanotechnology Initiative (NNI) has taken a leadership role in addressing issues confronting the development of nanotechnology. Positives include the leadership role of the NNI, interdisciplinary cooperation, support of university research, and interagency cooperation between and among the agencies and departments of the federal government. Negatives include insufficient focus to the NNI's nine "focus areas"—and that *science and discovery*, although a wonderful couple, are not enough.

Invention and innovation are required to transform those discoveries into products. There is not enough focus on product development. The National Institute of Standards and Technology's (NIST) ATP opportunity (Advanced Technology Program) is one of the few government agency programs that is able to "fund the gap" between a new idea and a fundable prototype. Why is this important—because nano is a global competition—a competition with foreign governments (and their complementary economies) that do stress and fund commercialization.

According to Jim Von Ehr, II of the Zyvex Corporation, university funding is doing well but is unfocused; commercialization is not working as well as it should; the (costly) national lab system and its relationship to the economy should be redefined; and patent reform should occur sooner than later to avoid creating "patent thickets" that impede innovation [4]. The government's role in technology is to regulate and tax when required. He believes that the U.S. government is not supporting industry very well. Tax codes, accounting rules, financial reporting, liability procedures, and regulations should not be changed every year. The acquisition of talent by limiting foreign visas forces jobs overseas and losses to foreign competition. The U.S. industrial policy has become "come to school here, create new technology, go back to your home country, and commercialize it there."

In 2005, London outpaced New York in the number of initial public offerings (IPOs) and the United States received none of the largest 25. The Sarbanes–Oxley (SOX) Act of 2002 had a devastating effect on foreign investment in the United States. Before SOX, 90% of foreign funds were raised in the United States. Post-SOX, 90% of foreign funds are raised outside the United States. This demonstrates clearly how the government can impact the economy. The combination of the SOX policy and the inability to import high-tech talent drives jobs to other countries and companies out of business here. In summary: (1) move towards engineering, applications, and commercialization, (2) intensify focus on energy, healthcare, and nanomanufacturing; fund social impact studies when nanotech has a larger impact; and study environmental issues in a science-driven manner, and lastly, (3) industry will respond to incentives [4].

1.0.4 The Nano Perspective

We can safely say that without manufacturing there would be no nanotechnology—at least according to our definition. Upon implementation of the technology, we ask ourselves is it for the greater good? Will society as a whole benefit from this technology? Societal implications and technology have always been linked. We therefore should make things for everyone—at least in theory. In the perfect world, everybody should win. Nanotechnology is no different. We develop products for the greater good, for defense, for profit, for barter, and for numerous other reasons. Where does nanotechnology fit into this age-old relationship? The diversity of products, a few mentioned earlier, shows no signs of slowing. While reading, and hopefully studying, this text, please keep in mind how this new technology impacts products, develops new ones, and enhances our security and quality of life. Think also how this new technology can impact our fears as well as our hopes.

1.1 The Business of Nanotechnology

Although most will not admit it in public, and we do not indicate anything by stating this, most scientists are not particularly business savvy, and to be fair to scientists, most business folks do not know a hoot about science or technology—at least beyond the fundamentals. Although there certainly are exceptions to this general conundrum, do you all essentially agree? We therefore have decided to include a *short course in business* in this textbook. The age of the *scientist as entrepreneur* is upon us as more and more universities interact with the commercial sector. Biotechnology first and now nano have pushed the envelope of interaction between academia and industry. As a future scientist or engineer, one must start thinking in terms of a career in nanotechnology, and even better, start thinking in terms of starting a business.

There are companies and there are nanocompanies. A nanocompany is not necessarily a small company. It may actually be a big company, perhaps a Fortune 500 company. What kinds of companies are drawn to this new technology? What differences are there between creating a nanotechnology company from say a biotech one? Nanotechnology has a high barrier of entry—unlike that faced by the "dot-coms" of the 1980s and 1990s—where all that was needed were a couple of geniuses, a PC, and a garage. Nanotechnology requires expertise (e.g., PhD level), costly equipment (e.g., transmission electron microscopes, ultrahigh vacuum), clean rooms, and highly trained tech people. Development and manufacture of nanomaterials, more than ever, also requires partnerships between and among government, business, and academia. Because nanotechnology is a worldwide phenomenon, competition is intense on a global scale.

The people and entities that support nanotechnology—the intellectual property managers, the patent attorneys, the building designers, the consultants—are all faced with new challenges brought on by nanotechnology and the interdisciplinary nature of the subject matter. Hopefully we will be able to raise questions, pose challenges, and explain some of what surrounds this global phenomena in the following sections of the text.

1.1.1 Background

Throughout history, humans have sought improvement by innovative approaches to the various tasks of living. Although the invention of stone arrowheads and spear points, the wheel, and a host of other early innovations precede written record, they were in by some perspectives more impressive in their impact on society than the invention of the electric light and telephone in the late nineteenth century. One characteristic of each of those early inventions is that someone accomplished the equivalent of starting a business. With the wheel, for instance, the wheelwright developed his skills to be able to make a consistently round product of a standard size.* The specialists able to run with these innovations were the forerunners of modern businesses.

The modern concept of a business, (e.g., a company with employees, products, a board of directors, a CEO, and shareholders) dates back only a few hundred years. Throughout history, however, the purpose of business was to sell products and services to buyers—the customers. From the time that early humans graduated from a simple hunter–gatherer status to increased levels of stratification with diverse skill sets, the equivalent of business was established. After all, what is the difference between a flint-knapper making arrowheads and spear points in exchange for food and shelter and a modern multinational corporation making electronic components in exchange for money? In terms of the lowest common denominator, the answer is nothing—both are trading one item of value for another at an agreed rate of exchange.

Over the millennia, this simple form of proto-business, essentially a sole proprietorship, began to evolve and grow into defined organizations offering a range of goods—from a bread maker with a few employees and several different products to a modern multinational corporation with thousands of products and tens of thousands of employees. At the same time, various restrictions, requirements, and other hurdles were put into place to make certain types of businesses more difficult to enter than others. From early on, businesses began to need some sort of registration with civil authorities, if for no other reason than tax assessment. Today, a business must register with the appropriate governmental agency in the country or state that it operates and must have various tax account numbers for payment of a variety of taxes. It also is responsible for various reporting requirements, depending on its structure.

Nanoscience and nanotechnology have already and will continue to yield many new and wonderful discoveries and inventions. But, as has been the case throughout history, these inventions remain interesting curiosities unless they are applied to develop products and/or processes that make their way into the mainstream of commerce. Take the wheel, for example. It is easy to understand that many applications, from the simple wheel/axle wagon to more complex

* Imagine what it would be like to have a chariot with different-sized wheels. If it were somehow impossible to make wheels consistently, would it have ever developed?

applications like block-and-tackle, watches, and precision gearing were made possible by applying the basic principle of the wheel. These are merely direct applications of the wheel. Indirectly, the wheel has led to many support products and even whole industries. For example, because wheels require lubrication, someone started manufacturing, marketing, and distributing lubricants. Others developed new materials to make the wheel last longer and perform better. Today, it is difficult to imagine a product or process that doesn't have a wheel somewhere within its mechanism. Nanotechnology has the potential to do the same. Indeed, many observers have stated emphatically that nanotechnology-based companies will engender another Industrial Revolution that is expected to exert profound effects on the world economy and society.

The U.S. National Science Foundation (NSF) has estimated that the world nanotechnology industry will grow from approximately $35 billion in 2005 to $1 trillion in 2015, employing over 2 million workers.* Such rapid growth is unprecedented but reflects a conviction that nanotechnology will affect and become a part of nearly every segment of industry over the next decade.

1.1.2 Companies

What Makes a Company? A company is not just a good idea, but is also a fine starting point. A company is a provider of goods and/or services that customers are willing to buy. It is also a person or a group of people able to supply those goods or services. This implies that the company is meeting some need, either existing or created.

The concept of an existing need is obvious, but what is a *created need*? The history of invention is the history of created needs. Nearly every adopted technology is either superior to an existing technology or it can outperform the previous technology. For example, conventional stoves and ovens are quite adequate for food preparation but the microwave oven provides an additional feature—convenience and speed in food preparation. Its development spawned an industry of prepackaged foods ready to "be popped into the microwave" and ready to eat in minutes. Later models were developed with oscillating or spinning cooking surfaces. A series of secondary products including "microwavable" cookware and special splatter covers appeared. Today, roughly a half century after the first microwave oven was introduced, most home kitchens and break-rooms in the United States have one.

The relevance of the example above is that not only can an inventor create a product and then a need for it, but also the acceptance of that product can spur the creation of a whole new industry. The entrepreneur needs to open his or her mind to the myriad possibilities for products, and therefore businesses, that can manifest themselves with the advent of new technologies, and their support. It will help the entrepreneur to consider exploitable market niches and products that will appear as the field of nanotechnology develops and expands its impact

* These numbers appear in Roco, M.C., *Journal of Nanoparticle Research*, 5, 181–189 (2003) and other sources from the same author. While this is a generally accepted figure, other sources place the market by the middle of the second decade of the twenty-first century as high as $2.6 trillion.

on society. Conversely, it will help the entrepreneur to understand what is displaced (and even disappears) as a result of a new technology.*

Successful entrepreneurs do not simply invent wondrous gadgets. They look at the gadgets they (or others) have invented and ask what could be needed to improve and to fully exploit and support them.

What Is a Nanotechnology Company? This seemingly simple question is actually a very complex one. One definition of a nanotechnology company is that it manufactures a product less than 100 nm in at least two dimensions, or that the manufacturing process itself is controlled at that size or smaller. The two-dimensional requirement would rule out companies making, for example, graphite lubricant because while sheets of graphene are one carbon atom thick (less than 1 nm), the other two dimensions are generally much, much larger than 100 nm. If a company were manufacturing coatings with particle sizes of consistently less than 100 nm, they would also qualify. However, we can safely call companies that manufacture thin films nanocompanies regardless of the lateral dimensions of their product. The process control issue would exclude bulk chemical manufacturers from joining the ranks of nanocompanies. Although chemical synthesis, as represented on paper, consists of reaction between atoms and molecules, the reality is that it occurs in 10,000 L reactors. The only real controls of these processes are physical in nature, for example, temperature, pressure, rate of mixing, rate and order of reactant addition, etc. By contrast, manufacturing an integrated circuit with components that are 65 nm in size do qualify as a nanotechnology process.

Nanotechnology companies also arise from the service sector. For our purposes, we define the service sector as comprised of companies that are not directly involved in developing or manufacturing a technology. Examples include:

- Consulting engineers specializing in the development of processes that fit the above definition
- Technology transfer professionals who seek out nanotechnology clients
- Patent law firms or agents having experience in filing and prosecuting nanotechnology-related patents
- Toxicology laboratories with the ability to study the effects of nanotechnology products on living organisms and the environment
- Contractors who were experienced in building the specialized manufacturing facilities needed or indeed a host of other service providers.

1.1.3 Sources of Nanotechnology Inventions

Although many discoveries and applications arise from work in laboratories of companies, a significant proportion, probably a majority of them, will originate

* For example, what happened to the typewriter industry when personal computers with word processors, such as the one used to write this book, became affordable and nearly universal? What about the typewriter repairman or ribbon and carbon paper manufacturers?

in academic and government laboratories, including both basic discovery and product development. However, these venues are not equipped to develop and commercialize products. The federal government mandates that research funded by the U.S. government be commercialized by a U.S. company. As a result, and over the years, institutions and laboratories have established bureaucratic structures and procedures for transferring newly developed technologies and products to U.S. companies. The general approach starts with the filing of a patent.* The university or national lab normally covers the cost of the patent filing. The invention is then licensed either exclusively or nonexclusively, usually for some fee plus royalties based on product sales, to a promising company. The terms for licenses vary considerably.†‡

Of course, many entrepreneurs who receive licenses from academic or government labs are in partnership (or will be soon) with the inventors employed by the institutions. Although the inventors understand the potential of the invention, not many have a clear idea of how to go about founding, registering, funding, and operating a company. The remainder of this section will provide a general overview of these subjects.

1.1.4 Founding a Company—What to Do First?

Most of the details you encounter below is nothing new—it applies to any and all businesses. Although nanotechnology is revolutionary in many ways, the structure of the business and the process required to move forward are relatively

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* When examining the patent status of the invention, the entrepreneur should keep in mind that nanotechnology is a worldwide effort and the filings need to be prepared such that they can be filed as geographically broadly as possible. A U.S.-only patent, commonly filed by universities and government labs, limits the value since anyone outside the United States can simply copy the technology and potentially produce products for sale in worldwide markets. The reason for limited filings by these institutions is not lack of understanding but lack of budget. The subject of patents is covered elsewhere in this book.

† License terms and negotiations are beyond the scope of this book and the reader is referred to the Association of University Technology Managers (AUTM, www.autm.org) and the Licensing Executives Society (LES, www.les.org) for more information about license terms and negotiations. Both offer courses on these subjects, for a fee.

‡ In the last decades of the twentieth century, many companies began to actively seek inventions and technologies from academic, government, and even other industrial sources and established professional positions devoted to the process of in-licensing of technology of potential value and secondarily out-licensing (or outright selling) of those no longer of internal interest. As a result of their experiences, a number of these technology transfer professionals have offered their services as consultants to companies seeking to acquire technologies. They can be found either by Web searches or through listings with the AUTM and LES. The entrepreneur with limited (or no) experience in this arena should seriously consider having professional help in negotiating terms to acquire rights to technologies and inventions. The role these professionals play is to help establish terms, generally financial and business terms (due diligence requirements, termination rights, and a host of other issues), but most of them are not attorneys and while they will also participate in contract negotiations they are not responsible for the actual contract drafting and language. An experienced commercial attorney is essential for this important task, with preference for one who has written contracts for closely related technologies.

ubiquitous and require a modicum amount of common sense. Students who receive degrees in science become good scientists but not necessarily good business people.

Before embarking on your entrepreneurial journey (always a wild ride), several questions need to be addressed. In doing so, the entrepreneur defines the company in order to decide what structure to use when registering it. These questions include:

- What type of company?
  - Manufacturing
  - R&D—contract or grant-based
  - Consulting
  - Service provider
- How much financing is required to launch the company?
  - Fees, including legal, to set up the company and obtain operating licenses
  - Salaries for entrepreneur, partners, and any initial employees
  - Facilities cost
  - Licensing fees for technology
  - Operational setup costs: supplies, Web site, office and laboratory equipment, and furnishings—everything that may be needed from paper clips and business cards to atomic force microscopes
  - Running costs until other sources of finance are available
- How will it be financed?
  - Entrepreneur alone
  - Insiders and family/friends
  - Angel/venture funding
  - Eventually through IPO
  - Product or service sales (with no need for outside financing)
- How will ownership be distributed?
  - Entrepreneur alone
  - Entrepreneur and partners or family members
  - Entrepreneur and financial backers
  - Employees through stock incentives
  - Large shareholder base through public offering
- Where will the company be registered?
  - If in the United States, which state?
  - If outside the United States, where?

All of these factors plus many others, including personal biases, play a role in the choice of structure. A good way to make certain these issues are considered is to write a *business plan*.

The principle purpose of a business plan, at least in the first draft form, is to focus the entrepreneur on defining the company in terms of products and markets, hurdles to success, financial needs, revenue and cash flow, personnel, facilities, and equipment needs. It will later be useful in raising money, whether from venture or angel sources or from banks but its greatest value to the entrepreneur is to his own understanding. It should include:

- Executive summary (actually written last)
- Company description—when, where, and by whom founded, assets, etc.

- Market served, including a market analysis
- Products
- R&D
- Manufacturing issues
- Management team
- Other personnel needs
- Hurdles and key milestones, with estimated dates and costs
- Financial analysis
  - Revenues and timing
  - Expenses and their timing
  - Break-even
  - Pre-revenue financing needs

It should be detailed enough to show that the potential entrepreneur has thought out the issues well but should not be too long (or no one will read it). As a rule of thumb it should be under 50 pages including financial tables and executive summary—that by itself should be a maximum of two pages.*

1.1.5 Business Structures

There is a wide variety of business structures in the United States. Since businesses are incorporated at the state rather than federal level, some variation in available structures that the entrepreneur in nanotechnology may consider are as follows:

- Various type of corporations
- Various forms of partnerships
- Limited liability companies
- Sole proprietorships

There are a few major characteristics that differentiate them. These include:

- Taxation status
- Liability to the owners
- Governance requirements (i.e., management and reporting requirements)
- Number of shareholders permitted
- Ease of raising capital

For instance, if the company requires a large capital budget to build the capacity to manufacture products, the most likely source would be through venture financing followed by a public offering of stock. This is best done with a General *C* Corporation. Venture capital funds, angel investors, and banks are familiar

* There are many sources of information and hints on writing business plans. Entering "business planning" into any search engine will turn up a large number of sites that will, sometimes with no fee, offer to help an entrepreneur with preparing business and marketing plans. Business plan software is available from several sources and can be found in many software stores. Reviews of business planning software can be found at www.homeofficereports.com/Business%20Plan.htm. There are also numerous books available from any bookseller. One that provides a good overview is T. Berry, *Hurdle: the Book on Business Planning*, Palo Alto Software (2002).

and comfortable with this structure. Investment bankers, for example, have experience with IPOs. Governance and reporting requirements for *C* Corporations provide a degree of confidence to investors that the company will be managed responsibly, or at least with shareholder and board of directors oversight, so as to provide the best possible return on the investments. The *C* Corporation fits the general image of a "company" in the minds of most: it has a CEO who reports to a board of directors, other corporate officers responsible for finance, R&D, manufacturing, HR, etc. To investors, it has two other important characteristics. The *C* Corporation can have an unlimited number of shareholders and a variety of classes of stock,* making it attractive as an investment assuming it also has products or potential products that could provide those investors a good return. Those products do not have to be ready to go to market in order to secure funding, but the company must produce sufficient data to show that they can be producing revenue in a timeframe acceptable to the investors.

A *C* Corporation also provides, in general, the most flexibility in offering ownership incentives to employees or outside service providers like consultants. Their compensation can include share grants either through outright sales or, as is more often the case, through so-called option grants to these individuals. This subject is an important one in light of recent U.S. Federal laws.†

If the company is a consulting business, the entrepreneur could establish a *sole proprietorship* or, if working with a partner a *general partnership*. These do not require registration but may require business licenses in some jurisdictions.‡ No special tax forms are needed because the income from the business flows into the owner's personal tax returns. The individual is personally responsible for all debts and obligations and therefore all personal property is at risk unless otherwise legally protected. Partnerships need to be structured very carefully since each partner is liable for all business debts and obligations incurred by the other partners, and in the case of sole proprietorships, all personal property is at risk unless protected by some means. In setting up a general partnership, care should be taken in putting together a partnership agreement (PA), a legal contract between the partners that governs the relationship. In general, this PA cannot

* In general, the class of common stock is what is traded on the various stock exchanges. Special classes of stock are often used when raising money before a public offering, and can have different values and voting rights, can even be interest bearing and include rights to convert to common stock at some fixed rate. When considering special classes of stock, legal advice is essential.

† For the interested reader, the Public Company Accounting Reform and Investor Protection Act of 2002, also known as the Sarbanes–Oxley Act, was passed in the wake of several corporate scandals, ostensibly to restore public confidence in corporate accounting practices. It has been the source of much controversy, with some claiming it interferes inappropriately with the operation of corporations, others claiming it does not go far enough, and yet others claiming that the arguments on both sides are overblown. This important act has had one effect that could be considered positive, the creation of a new line of business in software and consultation for compliance. Visit http://fl1.findlaw.com/news.findlaw.com/hdocs/docs/gwbush/sarbanesoxley072302.pdf for a full copy of the Act or use a search engine to find general articles that will provide some background.

‡ If the founder does not want to operate under his own name, he should register a trade name with his state authorities, the so-called Doing Business As or dba name.

limit an individual owner's liability for the business activities of other owners.*

Even though there is paperwork involved, instead of a sole proprietorship or a partnership, an entrepreneur should consider a structure that has the same tax consequences overall to limit their personal liability. Either a *Subchapter S Corporation* or a *Limited Liability Company* (LLC) will do that. The advice of an experienced business attorney should always be obtained before deciding the best type of structure for your business.

1.1.6 Registering a Company—Where?

In the United States, companies are incorporated (or registered) under state laws, not at the federal level. Each state has its own requirements for paperwork, reporting and taxation. While a company can register in any state, it generally needs to have an office, or *Registered Agent*, in the state it chooses. Many U.S. companies, especially those expecting to operate in several states, choose to register in a state that has advantageous tax or other corporate policies, often Delaware or Nevada, though many states are changing business laws to make themselves more attractive. Information about these and other potentially attractive states can be found on various Web sites to help the entrepreneur understand the basics of registration.†

Companies must also register in the state in which they are physically located or in which they have offices, employees, or other facilities, even if their primary registration is in one of the so-called business friendly states. For instance, a company with offices and manufacturing facilities in North Carolina, may choose to register in Delaware but then must register as a "foreign" company in North Carolina. If it establishes a research site in South Carolina or a sales representative with an office in California it will then register in each of those states as a foreign company as well.

An entrepreneur may initially decide to register the company in the state in which offices and laboratories are located. This may be done to reduce paperwork, including the filing of multiple tax returns and annual reports. If the business expands to several states, the primary registration can be relocated to one of the business friendly states. However, the list of these states is growing as more and more are competing for businesses, so such a move should be carefully investigated before any action is taken.

The business of nanotechnology is worldwide and although the above discussion has centered on U.S. companies and registrations, many of the same issues face the entrepreneur who wants to start a business elsewhere in the world. Of course, registration and corporate structures, though similar, vary from country to country.

* Except that the limited liability partnership can shield each partner from malpractice by other partners.

† Two such sites are www.mycorporation.com and www.corporate.com, though a search engine will also provide other sources. These sites not only provide information but also will aid the entrepreneur in registering his company in one of those states. Many business attorneys will assist in preparing registration documents, ownership contracts, bylaws, etc. and will act as registered agents for the business.

The nanotechnology entrepreneur may decide to establish subsidiary companies in countries other than the one in which he initially establishes his organization. Intergovernmental commercial treaties are in place to make the establishment of whole- or majority-ownership of corporate subsidiaries in countries other than the residence of the parent relatively easy—although various rules and restrictions may apply. In general, due diligence must be exercised if an entrepreneur wishes to establish a presence in multiple countries, for example, consulting legal entities for advice both in the home country and the foreign country is recommended. Information about the requirements and costs of registration in a wide range of countries is readily available on the Internet.*

Registering a Company—The Process. The Internet has changed the way businesses are registered. As late as the 1990s, a person wishing to register a company in the United States would have to obtain a form, fill it out manually, and either mail or carry it to the business registration office in his state, along with a check, sometimes certified, to pay the fees. Today, most states encourage registration via online forms and even charge a premium for using a paper form. Online registration has become streamlined so that someone who has registered several companies can usually complete the process in 15 min or less, and then pay the fees by credit card, never leaving his office.†

Once the company has been formed and registered, the entrepreneur needs to prepare the paperwork: company bylaws, employment contracts, quarterly (or even more often) and annual reporting to tax authorities, and many other details. Regular meeting of the board of directors is required as is an annual meeting of all shareholders. There are many more requirements that differ with the size of the company. Many of these details are both time consuming and tedious, but they have to be done or the company could be liable for various penalties. The entrepreneur, especially the scientist, is wise to either be prepared for paperwork or consult a business-oriented professional.

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* A Web search can be made for individual country registration requirements by using a search engine and a simple search string such as "business registration (country name)." A World Bank Web site: http://www.doingbusiness.org/ExploreTopics/Starting Business/ contains a broad compilation of estimated costs and registration requirements for all countries. U.S. embassies around the world have an officer known as the commercial attaché on their staffs. Many other countries have similar positions. The job of the attaché is to assist companies in understanding the business climate in these locations and helping businesses make appropriate contacts and negotiating the paperwork. These individuals and their staff can be a valuable resource.

† Once the company has been registered in the United States, the next step is to obtain an employer identification number from the Internal Revenue Service (IRS). This, too, is done online by going to the IRS site, www.irs.gov, and filling out and submitting Form SS-4, Application For Employer Identification Number. The number is assigned at the time of completion and a copy is mailed to the filing address. It may be necessary to obtain other permits and licenses from the state or states in which the company is registered, such as a sales tax license or a tax exemption number. In some jurisdictions a city or county tax or other permit may be required. Most of the applications for these are now available online and many, if not most, of them can be filled out and filed electronically.

1.1.7 Finances

Financing is the single-most important aspect of a new business. While this may seem obvious, one of the biggest problems for the entrepreneur is determining, and then acquiring, the amount of money needed to sustain operations until the company has sufficient product sales to pull the load. Unless the entrepreneur is already wealthy and can either fund the company from his own pocket or has partners, friends or family with money, time needs to be spent, perhaps a great deal of time, soliciting interest in his company from groups that do have money and who may be willing to invest it. After investing their own money and that of partners, family, and friends, most entrepreneurs turn to angel investors, venture capitalists, and then public equities markets. Angel investors are individuals or groups who invest their own money in companies that interest them. Usually the investment is small, under one million dollars (and often much less), and the investor receives equity in the company, sometimes a board position.*

Venture capitalists (VCs) are professionals who seek out investments for large funds they manage. These funds tend to be very large and investments they make are measured in millions of dollars. Venture capital fund managers have a reputation of being very exacting in choosing companies for investment. They often will want to participate in governance via board positions and may also demand preferred stock.† VCs have extensive contacts in the investment banking industry and can provide invaluable assistance when seeking additional finance via other venture funds, loans, or public stock offerings.

Capital markets, or stock exchanges, were established to provide an avenue for raising capital to finance major manufacturing businesses. In the United States, many business owners and investors are familiar with companies trading on the New York Stock Exchange and the NASDAQ system. However, there are public equities markets in every country and trading shares, via the Internet, that are able to facilitate investment. There is no reason to consider only the major U.S. markets (there are other stock exchanges in the United States and globally) as sources of capital. Increasingly, companies are choosing to register shares for sale on markets in Canada, various European countries, Singapore, Hong Kong, and others.

1.1.8 Managing the Company

Management, especially in a technical setting, is a complex and often delicate task. Entire racks of books about management can be found on the shelf and in

* Some entrepreneurs will balk at this. The author's advice is not to do so, since the angel investor usually has been successful in business and can offer valuable help in managing the company. Also, he is likely to know other potential angel investors or venture capitalists. When seeking more capital, such contacts are indispensable, and will provide more credibility than anything else, with the possible exception of a marketed product.

† Preferred stock can come in many different forms, but is "superior" to common stock. This means that if the company is sold or liquidated, the holders of these types of shares receive preference in any distribution.

the catalog of any bookseller. Numerous case studies have been published about successful and unsuccessful management practices. The subject is too large to address in this text but from the author's point of view, the most successful approach to management is respect. Employees at all levels who feel they are treated with respect will help make a company succeed by working harder and longer hours. On the other hand, an atmosphere of disrespect often results in underperformance and, sometimes, outright sabotage.

The most important task of the senior managers of any company is understanding the strategic goals and plans of the company and keeping themselves and their employees focused on them. This is especially important in a small, growing company.

1.1.9 Developing and Manufacturing a Product

This complex subject will vary over a wide range depending on the product. Product development and process development go hand-in-hand: the world's finest mousetrap will not be a success if it cannot be manufactured consistently and at a cost that makes it affordable to the consumer while providing a profit to the manufacturer.

For certain products, the development cycle is quite short because of facilitated production. A good example is the manufacture of carbon nanotubes formed by chemical vapor deposition. If purification and other properties are not considered, the cost of production is very low and fairly well understood. Thus, a new company entering this field could be selling product within a few months.

For others, the cycle may be very long. An example may be a nanoparticle drug delivery system. Besides the extensive testing any pharmaceutical product requires, that is, years to show both safety and efficacy, there may well be additional testing of any effects on the environment that may arise as a result of its manufacture or use. Another such product could be a nanoparticulate coating for glass to reduce glare or transmission of a certain wavelength. Such nanoparticles are expected to enter the environment as a result of the use of coated glass and data on the effects of that exposure could take a significant effort to produce and analyze. Such testing should be carried out or the manufacturer could be held liable for any problems.*

Building a manufacturing facility will also vary greatly with the product. Integrated circuit manufacturers working at the nanoscale will invest billions of dollars in manufacturing facilities, equipment and training, as will manufacturers of bio-nanotechnology products. A company manufacturing the window coating mentioned above may well be able to do so for a much smaller investment.

Product development and manufacturing are areas that the entrepreneur in nanotechnology should be very careful when considering. They can be very expensive in both time and finances and under- or overestimating the time and cost is very easy to do. With the advent of numerous and ingenious bottom-up fabrication processes, the cost of manufacturing can be driven to reasonable levels for start-ups.

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* The asbestos litigation is an example.

1.1.10 Marketing

The old adage that "if you build a better mouse trap the world will beat a path to your door" is only partly true. The world needs to know the mousetrap exists and where your door is located; and then it needs to know why it is a better mousetrap. That is the function of marketing.

For every shelf of management books at a bookseller there are at least four shelves of books about marketing, advertising, and sales. These books when taken collectively contain conflicting messages and methods about how to go about developing a marketing and advertising campaign and then selling the product. An entrepreneur with little or no marketing experience may not want to indulge in marketing strategies. When the company has a product identified and has it under development, the best approach is to hire a professional marketing person—let them develop and execute the marketing plan.

1.1.11 Exits

Once a nanotechnology company is successful, generally by having a product either ready for market or actually producing revenue, the founders are often faced with a choice: to stay on and manage a commercial operation or move on, allowing professional managers with the appropriate experience to take over. This is actually a difficult subject for many entrepreneurs. They have seen their company succeed and they often want to continue to grow the enterprise. The problem is that while a start-up company often needs the single-minded drive, enthusiasm, direction and, even, charisma of the founder, when it comes down to actually producing products and making a profit, management needs to evolve—a condition more evident if the company has become publicly held through a stock offering. In this case, the company comes under pressure from stock markets to increase revenue and profits. The type of executive manager who focuses exclusively on that issue, while still supporting new ideas and growth of product lines, is needed to manage the company in that environment.

At this point, the founders can choose to remain, perhaps in different roles, or leave the company. If they remain, they need to understand the differing needs and be willing to put the appropriate management into place: finance, marketing, R&D, manufacturing, HR, legal/patent etc. They then should act as enablers, helping and supporting these managers to do their jobs and make the company even more successful.

Leaving, although traumatic perhaps for both the founders and the associated staff, may be the best choice. Very often, founders leave and use the assets they have from their company to start other companies or to act as sources of funding for other entrepreneurs.* The successful exit is defined by another mechanism. Successful small companies (those that actually develop products and make a profit selling them) are very likely to be bought out by another company. If that small company is publicly-traded, the stock market sets a value

* In fact, the author has known a number of "serial entrepreneurs" who, having been successful with their first company, have gone on to found others based on different technologies or applications. Since they have a track record of success they often find it easier to attract financial backers in subsequent companies.

based on share price. How markets value traded companies is generally based on a multiple of earnings or potential earnings per share per year. The market capitalization is simply the per-share trading price at the close of any day multiplied by the number of shares actually issued to shareholders (as opposed to being held in reserve by the company) and, therefore, varies with the trading price. Usually, when a company is being sold, the total price is more than the market-based valuation, with the premium resulting from the negotiating acumen of the company being purchased.

If the company is not a public company, the sale price is determined by negotiations. If an entrepreneur is involved in selling a company with a revenue and profit stream it should be possible to calculate a value, taking into account future product revenues. If there is no revenue stream, the value is based on a model of future cash flows. It would be advisable to engage the services of a business evaluator with experience in high-technology companies to calculate a market value when revenues are either very low or not yet realized. Some of the best sources of such evaluators are the large accounting firms, who all have consulting arms prepared to do this kind of evaluation.

The above description of the founder being successful and able to exit the company with significant assets, that is, money or its equivalent, is the dream of all entrepreneurs. However, the reality of business is that many do not succeed. The technology often times cannot be developed in a commercially feasible form due to the lack of money, or that a competing product appears first, or for a wide range of other reasons. This situation does not necessarily cause bankruptcy. In fact, most businesses in the United States that close their doors do not owe money; they just do not succeed.

When the decision is made to "wind up" a company, that is, close it down, there are often assets left in terms of cash, equipment, intellectual property, etc. Many of these assets are sold or, as in the case of a lease of space, transferred to another company. the resulting cash is usually divided among the shareholders pro rata, with holders of preferred shares receiving the distribution first.

Many successful entrepreneurs have been through the closing of a company. It is not a reflection of failure on their part. They learn from the experience and then go on to found other companies.

1.2 Education and Workforce Development

Societal components collectively and integrally bend, mend, and mold our civilization. We now direct our attention to education and workforce development. With regard to the broader sense of societal implications, specifically that new technology brings along changes that are positive, negative, or indifferent, we will do our best to achieve a balanced presentation. We strive in this section to stay below and beyond the hype associated with nanotechnology, a technology and societal driver that pundits around the globe consider to be revolutionary.

As a student, you are standing at the threshold that opens into your future, your livelihood, and your potential contribution to society. The underlying purpose of this section is to inform, provoke thought, stimulate, and hopefully, to encourage direct action. One must seriously consider the following prediction by the NNI to understand the significance of what is to come. Specifically, that products impacted by nanotechnology are expected to contribute over $1 trillion to the global economy by 2015 [5]. The strategic plan released by the NNI in December 2004 opens with the following vision [2].

> The vision of the National Nanotechnology Initiative is a future in which the ability to understand and control matter on the nanoscale leads to a revolution in technology and industry.

This vision indicates a revolution (from the Latin *revolutus* to "turn, roll back," with the "general sense of great change in affairs") is in the making based on the promise of nanotechnology; a revolution that has the potential to radically transform both technology and society. We need to simply look back a few years to the twentieth century to understand the impact of new technology. The legacy of the automobile, the television, and the computer are well understood. Are nanoscience and nanotechnology capable of exerting such historical changes? The NNI strategic plan goes on to state [5]

> …the NNI will expedite the discovery, development, and deployment of nanotechnology in order to achieve responsible and sustainable economic benefits, to enhance the quality of life, and promote the national security.

The expectations for nanotechnology are quite lofty. **Goal 3** of the strategic plan is centered on the development of education and workforce development. The introductory paragraph of **Goal 3** emphasizes the important link between education and workforce development and the all-important tangible infrastructure that must be in place, seemingly a priori:

> A well-educated citizenry, a skilled workforce, and a supporting infrastructure of instrumentation, equipment, and facilities are essential foundations of the initiative. Nanoscale science, engineering and technology education can help to (1) produce the next generation of researchers and innovators, (2) provide the workforce of the future with math and science education and technological skills they will need to succeed, and (3) educate the citizenry capable of making well-informed decisions in an increasingly technology-driven society.

For any responsible strategy, the vision, goals, objectives, and the timetable are identified well before any reasonable action is to take place. Our hope is to convince you that a career in nano or related fields will offer challenge, accomplishment, and most importantly, responsible change in society. We repeat once again the inspirational statement attributed to Nobel Prize winner Dr. Richard Smalley, "*Be a scientist—Save the world*" [6].

1.2.1 Technological Revolutions—The Workforce Point of View

Education, workforce development, infrastructure, and industry are intimately intertwined and have collectively defined much of our civilization for thousands of years. Once again we are confronted with a familiar conundrum—what is the exact meaning and potential impact of nanotechnology and why would it be considered revolutionary? In order to gain a relevant perspective, we must review some basic history. Several thousands of years ago, developments in agriculture and irrigation transformed the nomad into the farmer. Prehistory ended with the birth of civilization. Agriculture is a *practice* that is defined as the production and distribution of food. With the creation of sessile agrarian societies, the livelihood of the majority of the population was based on farming and affiliated occupations. With the accumulation of assets, and eventually wealth, the need for armies, rulers, merchants, and clerics followed suit as a division in classes ensued.

On the other hand, the Industrial Revolution was based on a single-minded *manufacturing philosophy*, more specifically, the mass production of products. The invention of the printing press by Johannes Gütenberg in 1447 was an incipient form of mass production. The Industrial Revolution happened relatively quickly compared to the fundamental one of agriculture, but there was still plenty of time to adapt. Although all offspring of the Industrial Revolution, products such as the television, automobile, and computer have sprung minirevolutions of their own. Throughout history, we have had revolutions based on a *practice* (agriculture), based on a *manufacturing philosophy* (industrial), based on a *fuel* (oil), based on *products* (steam engine, railroad, automobile, telephone, and computer), based on *nature* (biotechnology), and based on *size* (micro and nano).

The currently burgeoning revolution in biotechnology is so because of our greater understanding of the *disciplines* of biology, biochemistry, and genetics. And what of the contributions of micro and later on, nano? What brand do we place on the micro- and nano-revolutions? Micro and nano are of course prefixes that relate to size. We now actually have revolutions, micro earlier and now nano, based on *SIZE* and size alone! The drive to manufacture smaller and smaller components materialized in the first portable watch, created by Peter Heinlen in 1524. The integrated circuit became the embodiment of miniaturization that has now morphed into nanocircuits.

Because nanotechnology has the capability to affect every type of product made (to the best of our knowledge, everything is still made of atoms and molecules), new jobs are certain to follow suit once a great idea leaves the lab—at least to countries that value education and innovation (is that us?). Will we have to overhaul our compartmentalized approach to education to one that is fundamentally interdisciplinary? According to an accepted definition of revolution, these changes are supposed to represent radical and far-reaching consequences, both of a technological and social nature. With each and every revolution throughout our history, the time scale of change has been diminished from that of its predecessor—overall, from several thousands of years to a few decades today. Is a revolution in education and workforce development needed or should we plod on with the status quo?

1.2.2 The State of Education and Workforce Development

It is widely viewed that the status of science and engineering education in the United States, and perhaps the Western world for that matter, is in a state of decline. According to Nobel laureate Richard E. Smalley [6], the United States in particular is falling behind developing nations such as China, India, and industrialized nations such as Japan with regard to the generation of new scientists and engineers. There is not enough space in this section to offer proper treatment of the multifold and complex factors responsible for the apparent decline. Without the addition of tedious detail, it is generally accepted that (1) the United States is producing fewer engineers and scientists; (2) although still the leader, more and more intellectual property is being produced outside the United States than ever before; (3) more and more high-technology jobs are being shipped overseas; (4) the structure of K-12 education is not optimized to promote science and engineering; (5) higher education is generally considered to be under funded with increasingly higher tuition; (6) the influx of foreign intellectual talent is limited due to current emphasis on security and increased prosperity in other nations; and (7) significant commitment in time and effort with diminished employment expectation results in fewer home-grown graduate students in science and engineering. According to Richard Florida, the author of *Flight of the Creative Class*, global competition for creative talent will be the defining issue of the twenty-first century [7]. Please acknowledge that this brief list is not apocalyptic in its message, just a statement of accepted trends. Isaac Asimov is noted for stating

> Science can be introduced to children well or poorly. If poorly, children can be turned away from science; they can develop a lifelong antipathy; they will be in a far worse condition than if they had never been introduced to science at all.

At the juxtaposition of any revolution, especially one that is suddenly upon us, opportunity abounds for those that are prepared. There are many means of navigating the impending maelstrom based on two generalized factors: (1) acknowledgement that the world is changing and (2) adapting by necessity to that change just like our predecessors did thousands of years ago. Economic development groups across the country have three goals: (1) jobs, (2) jobs, and (3) jobs. A civilization without jobs is incomprehensible, intangible, and actually unimaginable. Without employment there is no prosperity, at least within the existing paradigm—the paradigm that defines our quality of life. Along with each revolution, job descriptions have changed, oftentimes drastically.

In 1958, Congress passed the National Defense Education Act following the launch of Sputnik. In 2005, Louis V. Gerstner, Jr., a former chairman and CEO of IBM, stated in a *Newsweek* article [8]

> America is no longer winning the skills race. South Korea, with one sixth of the U.S. population, graduates as many engineers as the United States. China graduates four times as many; India, five times as many. Just as more than half of America's current science and engineering work force is approaching retirement, the flow of foreign talent is starting to dry up. For the first time in my memory, we're at the wrong end of a brain drain, as foreign-born grads in science, technology and engineering either return home after getting U.S. degrees or stay home in the first place.

According to RAND Corporation reports, alarms concerning potential skilled labor shortfalls oftentimes are not always justified [9]. However, they go on to say that

> … although previously anticipated STEM workforce shortages have not materialized in the economic sense, the implications of a shortage of skills critical to U.S. growth, competitiveness and security justify continued examination.

1.2.3 Current Workforce and Education Programs

Awareness about the current state of education and the workforce is at a high level, especially with the onset of nano. New programs available to attract or create scientists and engineers are springing up in every nation. Factors such as the age of the existing workforce, dependence on foreign nationals and outdated curriculum coupled with declining federal funding, and the accelerated pace of science and discovery bolster the case for urgency. There is a fierce global competition to commercialize nanotech-based products. The United States does not necessarily have the lead. The NNI has defined the needs for education and development of a workforce of the twenty-first century, and is backing up their proposal with funding initiatives. Emphasis on nanoscience and nanotechnology must begin in the K-12 school system and extend through community college, university, and vocational schools [10].

Programs developed by the Nanotechnology Institute (NTI) in Pennsylvania serve as excellent examples of advanced thinking and multilevel partnerships forged among business, academia, and government that promote nanotechnology education and workforce development. The organization is a collaboration of academic and research institutions with a state-funded economic development group, the Ben Franklin Technology Partners of Southeastern Pennsylvania. The following excerpt from their Web site summarizes the NTI workforce development mission (http://www.nanotechinstitute.org/nti/index.jsp).

> A highly-skilled, technically trained, nanotechnology workforce will be needed if the region is to gain full value from the commercialization opportunities that nanotechnology will generate. The NTI is partnering with regional community colleges to anticipate this need by building the partnerships and securing the tools and resources to develop and implement education, training and workforce development strategies.

Nanotechnology as we have learned has a high barrier of entry. Nanotechnology will require highly trained scientists and technicians, but those jobs need to be in place to attract these special graduates.

1.2.4 The Workforce of the Future

The *knowledge worker*, a phrase invented by Peter Drucker in 1959, identified the emergence of a changing workforce, one that relied more on brains than brawn [11]. Robert E. Kelley wrote an influential book in 1985 called *The Gold Collar Worker: Harnessing the Brainpower of the New Workforce* [12]. In it he writes that American business is suffering from a *brain drain* due to severe mismanagement of its most valuable resource—*brainpower*. If you recall, the 1980s was the decade of the information age (*a.k.a.* revolution). Kelley stated that the gold-collar worker should

> …engage in complex problem-solving, not bureaucratic drudgery or mechanical routine; they are imaginative and original, not docile or obedient. Their work is challenging, not repetitious, and their results are rarely predictable or quantifiable especially if they're scientists or researchers. Gold-collar workers are everywhere…

According to Dr. Mary Ann Roe, the author of *Cultivating the Gold Collar Worker*, nanotechnology along with the other emerging technologies, will require a special workforce. She states that [13]

> Complex powerful currents swirl through the nation and the world, altering the economic landscape, while offering extraordinary opportunities for well-prepared individuals… Technology-driven, these currents propel dynamic change, force innovation and create new types of work in the private sector.

According to Dr. Roe, this belongs to the techno-professional who wears a gold-collar—an individual with a white-collar mind but blue-collar hands; a worker who is able to create as well as operate and think as well as do.

We try to envision the future and the worker therein. Within the lexicon of social prognosticators of this day and age, we are told often that the average employee changes job description, or the job itself, every five years. We predict that the new workforce, whether of white, blue, or gold collar, will have flexibility in the job market, a high level of training and education, an interdisciplinary background, advanced communication and computer skills, and perhaps an understanding of the international education and economic community. We boldly predict that the face of K-12 must change in order to accommodate the new age of technology. Instead of teaching to the test in a compartmentalized fashion, classrooms must open curricula to new ideas and efficiently teach interdisciplinary programs in the sciences. Partnership and close communication between educational institutions, the universities and community colleges in particular, and industry is necessary to ensure that there is balance between the needs of industry and a supply of educated and trained students. We are all aware of the shortage of trained technicians in the biotechnology sector.

1.2.5 Planning Ahead and Potential Career Paths

There is no guarantee of success. That key ingredient is always up to the individual. Contemplate for a moment the vast complexity of today's economy. Surely there are numerous paths to a fulfilling career. Make a list of potential paths for your future career. Then, try and integrate those paths with a nanotechnology theme.

The best approach begins with *planning* now. It is never too early to make plans. Therefore, start a *journal* to keep track of any ideas, thoughts, or references that happen your way. *Flexibility* is always a survival advantage. Omnivorous species like crows tend to out compete counterparts that rely on a limited food sources. Devour knowledge. Consider also that many of us end up doing work that we never intended to do. Nonetheless, a good strategy is to place your focus on one academic discipline such as chemistry but learn enough about physics, engineering, and biology to be able to understand your coworkers of the future. *Networking*, a good way to achieve that good strategy, is perhaps one of the most powerful tools that an individual can acquire. It really is "who you know" much of the time. Attend conferences—as many as physically possible. Open your horizons and *partnerships* to include business, academia, and government, the big three that are currently working together to pave the road for the nanotech revolution. Traditionally, business folks do not mingle much with academics. That tradition is changing drastically as universities are acquiring the entrepreneurial spirit and commercializing intellectual property like never before.

Research all available *funding sources*. Conduct investigations to find federal, state, local government, and private sources. For example, funding for women scientists and underrepresented groups are out there just waiting to be tapped. Stay abreast of *societal implications*, understand social and global trends, and track investments into nano-based businesses. Take a serious look into *careers that are tangential to the science and technology*. For example, there is a great need for a new generation of patent lawyers who possess interdisciplinary skills and knowledge. Health and safety, job sourcing and staffing, education at all levels, economic development, public policy, regulation, international commerce, and investment are but a few examples of jobs outside the technology. Lastly, and certainly of some great importance, make plans now to *start a nanobusiness*. Take care of your education (perhaps an MBA in the plan), do the research, conceive a novel product or process, make the contacts, establish the necessary partnerships, locate and secure funding and, yes, then you are in business. Although things "do come to those that wait," it is a much better policy to get informed and go after it. We wish the best of luck to you all.

1.3 Buildings for Nanotech

We now jump from creating and operating a business and finding and securing employment to buildings that house them. Nanotechnology along with biotechnology are placing exceedingly stringent demands on laboratory design, manufacturing strategy, and construction. This section presents a short introduction into another world—the domain of architecture and construction—where our new facilities try to keep pace with the *Nano Age*.

Old buildings are constantly being replaced due to wear and tear, but a new paradigm of building design, construction, and operation is upon us nonetheless and on many fronts. New buildings need to be designed and constructed to accommodate the rapid changes brought about by new technologies in the fields of biology and nanotechnology, new technologies that rely on interdisciplinary cooperation in a big way. New designs also include more efficient means to improve indoor air quality, electricity production, energy efficiency (heating), waste management, water conservation, and daylight lighting designs—some already enhanced by the new technologies.

New buildings also include environmentally approved technologies and practices that include use of recycled materials and reduction of toxic material components. Although we can spend a significant amount of time discussing new building philosophies and practices, we must focus on the relevant thrust of this chapter—how building and facility design and construction conform to the needs of nanotechnology and biotechnology—and conversely, how nanotechnology can contribute to new buildings. Now more than ever, the goals of research centers, are to conduct world class research, attract researchers and students, attract money, attract industry, provide jobs and, at the same time, be flexible [14].

Several "monuments to science and technology" have been constructed worldwide to support nanotech and biotech R&D. A few notable buildings are mentioned in this text: the Center for Integrated Nanotechnologies (CINT) of Sandia and the Los Alamos National Laboratories in Albuquerque, New Mexico; the Birck Nanotechnology Center at the University of Purdue in West Lafayette, Indiana, and the state-of-the-art leader amongst all buildings that support advanced technology—the NIST's Advanced Measurement Laboratory (AML) in

Gaithersberg, Maryland. We shall focus primarily on NIST's AML facility. Please refer to www.HDRInc.com, aml.nist.gov and www.nanobuildings.com for complete information concerning all of their advanced technology facilities.

1.3.1 Nanotechnology in Buildings—Environmental Aspects

Although we will present the strategy and design elements required in constructing buildings to support nanotechnology research, development, and manufacturing, it is only fair that we reserve this section to discuss the impact of the nanotechnology on building materials and construction in general. The construction business is estimated to be on the order of $1 trillion per year worldwide [15]. Many kinds of building materials already take advantage of nanomaterials [15]:

The Now

- Flexible solar panels
- Self-cleaning windows
- Self-cleaning concrete using catalytic TiO_2
- Wi-Fi paint (an additive mixed with paint that reduces transmission of radio waves through walls)
- Selective absorbing–reflecting solar windows
- Scratch-resistant flooring
- Antimicrobial steel surfaces
- TiO_2 and AgO antimicrobial coatings (public places)
- Nano-cement (enhanced physical properties)
- Nansulate coating (corrosion prevention, insulation)
- Translucent concrete (enables transit of light)
- Nanotech-enabled gypsum drywall (water resistant, durable, stronger, lighter)
- Nanotech-enabled steel (corrosion resistant, higher strength, high plasticity)
- Aerogel glasses (high R-value thermal insulation, acoustic insulation)
- Nanogel (Cabot Corp.) traps air at the molecular level → thin insulating layers

According to the USDA Forest Service Research Laboratory, nearly 2 million housing units were constructed in the United States in 2004 [16]. Wood comprised, by volume, 80% of all the building materials used. Half of the wood products are engineered wood composites. Nanotechnology is expected to contribute to the next generation of wood-based products that exhibit enhanced strength, properties, and endurance similar to those of carbon-based composite materials [16]. The new materials are designed to be biodegradable [16]. And of course, nanotechnology will promote the development of "intelligent wood"—biocomposite products with built-in arrays of nanosensors. By the way, wood is a natural nanomaterial. According to the USDA [16]:

> Building functionality into lignocellulosic surfaces at the nanoscale could open new opportunities for such things as self-sterilizing surfaces, internal self-repair and electronic lignocellulosic devices. The high strength of nanofibrillar cellulose together with its potential economic advantages will offer the opportunity to make lighter weight, strong materials with greater durability.

The U.S. Department of Energy's Twenty Year Plan identifies strategies for environmental friendly buildings—try and select the ones you believe involve nanotechnology. The United States has 5% of the world's population but consumes 25% of the world's resources and discards 40% of the world's waste, of which 50% is due to construction activities [17]. If we can at least optimize our buildings, perhaps a dent can be made on some of these statistics. We listed a few current innovative products enhanced by nanotechnology earlier. Let us continue by painting a picture of the near and far futures.

The Near Future

- Cellular building materials
- Disaster-resistant materials
- Intelligent materials (e.g., self-repairing, self-adjusting)
- Superior moisture barrier materials
- Nontoxic materials
- Resource-efficient materials
- Superior insulating materials
- Superior weather-resistant capability (e.g., low maintenance)
- Smart materials with sensors able to detect loads, temperatures, decay, fire, etc.
- Fiber-cement siding (self-cleaning, thin layer of silica)
- Anti-bacterial house fittings (Ag particles or light-activated particles)
- Fire retardant materials that incorporate clays
- Easy-clean water repellant surfaces
- UV-resistant paint coatings
- Thin film coatings for roofing materials

Other aspects of construction include household devices. Home and laboratory products enabled by nanotechnology include [18]:

- Water treatment systems (nanofiltration, light-activated nanoparticles)
- Energy-efficient lighting, LED, and electroluminescent lighting
- Solar energy generation and advanced energy storage

Buildings in the Not-So-Far Future [19]

- Earthquake-proof buildings using carbon nanotube reinforcement
- Nano-reinforced glass structural and enclosure elements
- Quantum dot lighting
- Next generation nanosensors

The interior lighting paradigm will also be impacted by nanotechnology—by solid-state lighting devices made with nanocomposite materials. Carbon nanotube-based organic composites, known as "ultra-low energy high brightness" (ULEHB) lights, are expected to produce the same quality light with a fraction of the energy. Many other materials are under development: self-healing concrete, UV-IR radiation blockers, smog-mitigating coatings, and LEWs and LECs (light-emitting walls and ceilings). According to George Elvin of Nanowerk.com, the "smart home" is also on the horizon. Smart homes are decorated with nanotechnology-based sensors that monitor temperature, humidity, and toxins as well as transmit medical information to your doctor. From larger structures to appliances, sensors would be able to monitor vibration, stress, crack propagation—the foundation for "intelligent buildings" [15,19].

There is no doubt that nanotechnology will impact (and has already impacted) the way buildings are constructed, the materials selected for building structure and function, and the way people interact within buildings. It is not hype. It is due to the remarkable properties of nanomaterials that there is the excitement and anticipation. Yes, there is hype out there and the nano-pretenders abound, but atoms and molecules do not spin tall tales—they just spin.

Through nanotechnology, we will be able to develop the building materials of the future—those that absorb and radiate heat, offer earthquake-proof stability, the electrical wires that conduct over long distances efficiently, windows that reflect or absorb radiation depending on the current need, solar cells that power our instruments, and cooling systems and lighting that do not damage our environment. Yes, it is possible to accomplish all of the above. Yes, much of it will, and already has, come from our knowledge of nanotechnology. The materials and processes just have to be cost-effective and competitive—complete with an analysis of long-range recovery of costs and comfort with environmental friendly interactions.

In the United States, buildings consume 39% of the total energy, 12% of the total water, 66% of the total electricity, and contribute to 38% of the total carbon dioxide emissions [20]. What can nanotechnology (and our own policies) do to help mitigate these numbers?

Environmental Protection Agency's (EPA) Elements of Green Building

- Energy efficiency and renewable energy
- Water stewardship
- Environmentally preferable building materials and specifications
- Waste reduction
- Toxic material reduction
- Indoor environment mitigation
- Smart growth and sustainable development

In addition to renewable energy sources, equipment and appliances should conform to EPA's *Energy Star* program—the Building Design Guidance [21,22]. Designers, architects, and builders should consider the following:

- *Include statement of energy design intent* (SEDI)—describes the energy performance outcome of your building in the bid package
- *Specify design team participation*—during construction to ensure that energy performance features are incorporated
- *Include approval process for change orders*—accountability!
- *Document construction methods*—include manufacturer's literature, summary of energy efficient features, and explanation of anticipated functions to assist construction team
- *Select qualified manufacturers*—rejection of unapproved alternatives and coordination of manufacturers to enhance compatibility
- *Seek incentives*—local utility company incentives and government incentives to offset costs
- *Communication of superior design intent*—label with Energy Star mark

What is a green building material [23–26]? A green material is made of renewable resources. The use of green building materials reduces the environmental impact of extraction, transportation, processing, fabrication, installation, reuse, and recycling and disposal [26]. Green building materials reduce maintenance-replacement costs over the life of the material, provide for energy conversation, improve occupant health and productivity, lower costs associated with changing space configurations, and offer greater design flexibility [26]. Material selection criteria, in addition to its suitability for the intended function, include resource efficiency, indoor air quality, energy efficiency, water conservation, and affordability [25,26].

The Leadership in Environmental Design. The Leadership in Environmental Design (LEED) is a green building rating system developed by the U.S. Green Building Council. The LEED concept sprung from the Natural Resources Defense Council (NRDC) in 1994 and a consortium of nonprofits, government agencies, architects, engineers, builders, developers, product manufacturers, and others [27]. Buildings are rated according to the following six criteria: sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, and innovation and design processes. Certification categories start at the baseline with "Certified" and then progress from "Silver" to "Gold" to "Platinum" with Platinum being the best possible rating.

1.3.2 The Needs of Scientists and Engineers (And Equipment and Instrumentation)

Architects and designers need to know what engineers and scientists require. There are, for example, several challenges that arise from integrating technologies. The transfer of energy across multiple length scales; optical amplification of quantum dots in a two-dimensional crystal; combining top-down with bottom-up fabrication; interfacing biological and synthetic systems; and interfacing mechanical force and fluid transport (e.g., nanomechanics and nanofluidics) at the nanoscale. Such integrated nanotechnologies are expected to impact our world, according to N.D. Shinn of Sandia National Laboratory in New Mexico, who states "… connecting scientific disciplines and multiple length-scales is the key to success," and require special buildings to house processes and procedures [28].

The CINT model is a prime example of an integrated building in which integrated science is accomplished. CINT makes use of a "core-gateway model" that emphasizes interaction between two national labs (Sandia and Los Alamos) and universities. More about CINT is presented later in this chapter.

Nanotechnology research requires observations of reactions in real time (at femtosecond time scales or lower). Nanotechnology research requires increased resolution—the capability to see atoms and gauge the level of material behavior at the molecular level without interference from the outside world [29]. The underlying goal of every new advanced technology building is to, of course, have built-in flexibility [14]. Collaboration, interaction, and integration are key components of any new design—and these ingredients must all coexist within one building or complex. A case in point is the interdisciplinary collaboration among multiple disciplines and interaction between academia, business, and government. In addition, new buildings, need to accommodate technology transfer like never before, evolve into a technology transfer user facility [14].

Interactive Spaces. A state-of-the-art research and manufacturing center is composed of many kinds of *spaces*—the result of forethought, adaptability, and an effective floor plan design. *Technical spaces* are places where characterization, laboratory work, and manufacturing are accomplished. These include clean rooms, imaging facilities, production (e.g., lithography), and metrology. *Nontechnical spaces* include offices, meeting rooms, libraries, conference rooms, and auditoriums. These spaces must be strategically placed around, within, or between technical spaces to enhance interaction between and among scientists, entrepreneurs, and managers.

A key element of advanced building design that is acquiring exponentially more importance with each passing year is the following—how do the architect and engineer accommodate the increasing level of interdisciplinary needs required for nanotechnology? We will need dry labs, wet labs, semiconductor clean rooms, bio-clean rooms, quiet labs, ultraquiet labs, labs for metrology and imaging, office spaces, interactive spaces, and spaces for support. Potential users may arise from numerous university departments—chemistry, physics, biology, chemical engineering, mechanical engineering, agronomy, mathematics, biophysics, computer sciences—and from industry and government.

Environmental Considerations [29]**.** Environmental stability is important in any laboratory or manufacturing facility. Factors that contribute to environmental stability include temperature, humidity, contamination, air velocity, and vibration. Environmental stability is defined over space (uniformity) and over time (drift) [29]. Uniformity is influenced by the amount of "in and out" of a room, the distribution scheme, and the room design. Drift is influenced by measurement and control systems, sensor locations, and equipment placement.

Temperature and Humidity. Temperature control for a room that houses a TEM is a challenging prospect. The room temperature surrounding a high-powered (+300 kV) TEM should conform to 20 ± 0.01 to 0.25°C. The drift of temperature should be no more than $0.5°C \cdot h^{-1}$ (fluctuation $0.05°C \cdot min^{-1}$) and air velocity less than $5\,m \cdot min^{-1}$. The heat generated from a generic TEM column and support equipment is 500 W and 800–1200 W respectively. In order to achieve ca. control, internal sources of heat gain need to be minimized (e.g., lighting), a high air exchange rate needs to be maintained ($>300\,AC \cdot h^{-1}$), and heat transfer through walls needs to be minimized [29]. Added features such as a heated floor pad aid in maintaining such a tight rein on temperature.

Humidity control, obviously, is vital for several highly sensitive measurement techniques. For example, the temperature and humidity requirement for JEOL's JXA-8200 electron probe microanalyzer is ±1°C and 60% rh or less so that dew does not condense on the cooling water hose. At NIST's AML, humidity control is exerted to a level of ±1% in metrological areas and ±5% in other laboratories.

Clean Rooms. A clean room (or cleanroom) is an isolated space within which a high level of particulate contaminant control is in effect. A clean room environment is designed to reduce environmental pollutants such as dust, microbes, aerosol particles, and chemical vapors [30]. According to ISO-14644 (The International Standards Organization)

Table 1.2 *United States Clean Room Standards*

US FED STD 209E	≥0.1 µm	≥0.2 µm	≥0.3 µm	≥0.5 µm	≥5 µm
1	35	7	3	1	
10	350	75	30	10	
100		750	300	100	
1,000				1,000	7
10,000				10,000	70
100,000				100,000	700

Source: US FED-STD-209E Cleanroom Standards. With permission.

> Cleanrooms and associated controlled environments provide for the control of airborne particulate contamination to levels appropriate for accomplishing contamination-sensitive activities. Products and processes that benefit from the control of airborne contamination include aerospace, microelectronics, pharmaceuticals, medical devices, healthcare, food, and others. Many factors besides airborne particulate cleanliness must be considered in the design, specification, operation, and control of cleanrooms and other controlled environments.

This is no easy feat to accomplish considering that the air outside in a typical city has on the order of 3.5×10^7 particles $\cdot$ m^{-3} 500 nm or larger. Microprocessors, for example, are assembled in a clean room. Other aspects of clean rooms such as temperature, humidity and pressure are also strictly regulated.

According to Federal Standard 209E, a *Class 10000* clean room should have no more than 10,000 particles larger than 0.5 µm in a cubic foot of air. A *Class 100* clean room should have no more than 100 particles larger than 0.5 µm in a cubic foot of air. A *Class 1* clean room should be essentially contaminant free (**Table 1.2**). Hard disk manufacturing requires a Class 100 clean room. The ISO, headquartered in Geneva, Switzerland, also recommends standards for clean rooms based on a logarithmic scale.

ISO-14644-1 Standards. Following normalization between cubic feet and square meters, clean room standards are converted accordingly: *Class 1* = ISO 3, *Class 10* = ISO 4, *Class 100* = ISO 5, *Class 1000* = ISO 6, and Class *10,000* = ISO 7 (**Table 1.3**). Other standards are also in existence.

Table 1.3 *International Standards Organization Clean Room Standards*

ISO-14644-1	≥0.1 µm	≥0.2 µm	≥0.3 µm	≥0.5 µm	≥1 µm	≥5 µm
ISO 1	10	2				
ISO 2	100	24	10	4		
ISO 3	1,000	237	102	35	8	
ISO 4	10,000	2,370	1,020	352	83	
ISO 5	100,000	23,700	10,200	3,520	832	29
ISO 6	1,000,000	237,000	102,000	35,2000	8,320	293
ISO 7				352,000	83,200	2,930
ISO 8				3,520,000	832,000	29,300
ISO 9				35,200,000	8,320,000	293,000

Source: International Organization for Standardization (ISO-14644). With permission.

Air entering a clean room is filtered for dust and the air inside is recirculated through high efficiency particulate air (HEPA) and ultra-low penetration air (ULPA) filters. Employees in a clean room facility must enter through airlocks that may contain an air shower and wear bunny suits that cover all of the person including hands and shoes. Any fibrous or particulate materials are prevented from entering the clean room (e.g., pencils, fabrics, soda pop). Clean rooms also maintain a positive pressure within to prevent egress of unfiltered air. The support equipment infrastructure and maintenance of a clean room (air conditioning, filter systems, etc.) may be enormous and complicated respectively.

Electricity. According to the IEEE (Institute of Electrical and Electronics Engineers) Std. 1100–1999

> Power quality is the concept of powering and grounding electronic equipment in a manner that is suitable to the operation of that equipment and compatible with the premise wiring system and other connected equipment.

Power disturbances arise from external or internal sources. External sources include lighting, faults, and utility switch surges such as voltage reduction and line maintenance. Internal sources arise from mechanical equipment (chillers, fans, pumps), elevators, shop equipment, and laboratory equipment. There are several means of reducing electrical disruptive effects by applying power conditioners, transient voltage surge suppressors reduction (dedicated circuits minimize line noise, transients), shielded-isolation transformers, uninterruptible power supplies (UPS), and standby generators [31].

Common and normal mode transients from line and load side sources, noise from and between lab equipment, stray ground currents, ELF (extra or extremely low frequency) and EMI (electromagnetic interference) sources, acoustic noise sources, vibration sources, irregular voltage and frequency, and sources of heat are some common problems facing architects and engineers who design any laboratory. With nano-capable equipment, such issues are exacerbated and special care must be taken to minimize electrical disruption so that they do not influence data acquisition and measurements. System wiring configurations also play an important role in reducing electrical disruptions. For example, grounding systems include lightning protection, safety wiring, communication system grounds, signal reference grounds, and instrument reference grounds. Isolated grounding of individual equipment is recommended [31]. For more information, please refer to www.HDRInc.com.

Vibration and Acoustics. Structural and mechanical design of advanced technology facilities must address vibration-sensitive issues [32,33]. Mechanical vibrations in general, depending on energy and their potential targets, can be detrimental to human health, comfort impairment, sensitive equipment, and structural components [34]. Many laboratory operations are sensitive to vibrations. These include metrology, high-end imaging (TEM, SEM), photolithography, and probe development [32,33]. Other methods and procedures are impacted by vibrations to some degree. These include optical microscopy, mass spectrometry, and other characterization methods. Low-end imaging, theory and modeling instruments, and nontechnical spaces, of course, are less sensitive to vibrations. The bottom-line, like for any requirement, must be balanced with cost-effectiveness, facility mission, aesthetics, facility operation costs, and future flexibility.

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Sources of external vibration are numerous. Machinery, road traffic, and continuous construction activity are considered to be sources of *continuous vibration*. In this form, vibration continues uninterrupted for a defined period. *Impulsive vibrations* are infrequent and sporadic and are defined as "three distinct vibration events in an assessment period" (e.g., dropping heavy equipment and loading and unloading supplies). Rapid buildup to a maximum level followed by a damped decay of short duration is a characteristic of impulsive vibrations. *Intermittent vibrations* arise due to trains, passing heavy vehicles, and intermittent construction activity. Intermittent vibrations can be interrupted periods of continuous vibrations or repeated periods of impulsive vibrations that arise from continuous or repetitive sources.

Internal sources arise from periodic excitations (e.g. constant speed rotating equipment), footfall (e.g. from the scientists), AVAC, fluid transmission in pipes, and low-frequency airborne acoustic noise (e.g. chit-chatting) [34]. The effect of mechanical vibrations depends on the vibration amplitude, frequency range, duration, the predominant component, and time of day [34]. There are several standards that describe recommended vibration criteria (VC).

VC Curves. Generic vibration criteria curves are provided to architects and engineers who design housing for vibration-sensitive instruments [35]. With the onset of the microelectronics, medical, and biopharma industries in the 1980s, *criterion curves* were developed to lay down generic standards for vibration for a wide range of instrumentation, equipment, and tools.

The VC curve is represented in the form of a set of *one-third octave band velocity spectra* [34,35]. The curves are defined in terms of constant velocity (RMS) within the 8–80 Hz frequency range. The energy-averaged RMS velocity is calculated within proportional bandwidths, for example, a one-third octave bandwidth spectrum at each frequency range that lies within 23% of the center frequency (or 71% of the peak value) and is considered in all three orthogonal directions [34]. RMS velocity (as opposed to the "peak" or "peak-to-peak" criteria) is measured in terms of $\mu m \cdot s^{-1}$. The RMS velocity is related to the product of the frequency f and the wavelength λ (displacement) of the vibration. Displacement, velocity, and acceleration are all interrelated.

$$\upsilon = 2\pi f \lambda \tag{1.1}$$

VC curves extend from 4 to 100 Hz. Pneumatic isolation systems (e.g., for AFMs) may resonate with floor vibrations in the 1–3 Hz range. There is usually less concern for vibrations above 100 Hz. Relevant generic vibration criteria for advanced buildings are as follows: VC-A/B $\rightarrow$ 50 to 25 $\mu m \cdot s^{-1}$; VC-D/E = 6 to 3 $\mu m \cdot s^{-1}$; NIST-A $\rightarrow$ 0.025 μm displacement for $1 \le f \le 20$ Hz or 3 $\mu m \cdot s^{-1}$ for $20 \le f \le 100$ Hz; and NIST-A1 $\rightarrow$ 6 μm displacement for $f \le 5$ Hz or 0.75 $\mu m \cdot s^{-1}$ for $5 \le f \le 100$ Hz [35]. Each instrument has a unique RMS υ versus f profile. For example, *Omicron AFM* VC criteria lie within 0.5 and 1 $\mu m \cdot s^{-1}$ ($1 \le f \le 10$ Hz); a *Mann 3696 Stepper* is 0.8–80 $\mu m \cdot s^{-1}$ ($1 \le f \le 100$ Hz); a *Hitachi S-4700ii SEM* range is 10–20 $\mu m \cdot s^{-1}$ ($1 \le f \le 10$ Hz); and a *JEOL 2010 HRTEM and 6400 and 5800 SEMs* are 6–20 $\mu m \cdot s^{-1}$ ($1 \le f \le 10$ Hz).

For offices and theory and modeling facilities, RMS velocities between 400–800 $\mu m \cdot s^{-1}$ are tolerable. General labs fall into the range of 50–100 $\mu m \cdot s^{-1}$ (VC-A±). Clean room levels depend on the designation of the clean room: Class 1000 $\rightarrow$ 25 $\mu m \cdot s^{-1}$ (VC-B); Class 100 $\rightarrow$ 6 $\mu m \cdot s^{-1}$ (VC-D); Class 10 $\rightarrow$ 3 $\mu m \cdot s^{-1}$ (VC-E). Metrology lab VC criteria range from 3–6 $\mu m \cdot s^{-1}$. AFM and atom pushing

≈3 μm · s^{-1} (VC-E or NIST-A) and nano-instrument development is defined under 1.25 μm · s^{-1} [32,33]. Vibration limits in general for nanolabs of 0.75–3 μm · s^{-1} are not unusual [36]. More information about vibrational concerns, criteria, and recommendations can be found on www.colingordon.com.

Electromagnetic Shielding. Electromagnetic field (EMF) shielding is the process of reducing the intensity of EM radiation between two areas. Placing a barrier made of a conducting material is able to accomplish this task. In particular, sensitive equipment needs to be shielded from radio frequency-electromagnetic sources (RF-shielding). Such shielding (e.g., Faraday cages) diminishes the interaction between radio waves and electrostatic fields. Magnetic shielding may also be required. TEMs, SEMs, E-beam writers, and semiconductor inspection systems are some examples of sensitive equipment that require shielding.

Mechanical Noise. Noise is measured in terms of decibels (dB). A *decibel* is a dimensionless unit of measure that gauges the intensity of sound. It is a measure that is used in electronics, signal transfer, and communications. The dB is the logarithm of a ratio—the ratio may be that of power, sound pressure (acoustics), voltage, or other indicators of intensity. The sound-intensity-level dB(SIL) decibel reference is standardized to the level of threshold intensity of hearing in humans in air—ca. 1 kHz with an intensity of $I_o = 10^{-12}$ W · m^{-2}. One decibel is

$$1\text{ dB} = 10\log\left(\frac{I}{I_o}\right) \tag{1.2}$$

or in other words, 1 dB equals ten *bels*. The exponent of the power of ten in the final log term is known as the bel.

The dB(SPL) is the decibel (sound-pressure-level) relative to 20 μPa (2×10^{-5} Pa), the minimum sound a human can hear in air (e.g., a mosquito at 3 m distance). Other symbolism is used depending on the frequency scale used for calibration. The dB(A), dB(B), and dB(C) are based on different frequency weighting. For example, dB(A) is based on the A-scale range. Some nighttime zoning restrictions call out a maximum of 45 bB(A). Ambient noise is not to exceed 55 dB (10 Hz < f < 10 kHz) within 0.5 m surrounding an electron microscope as specified by the manufacturer [36].

The primary source of mechanical noise arises from HVAC (heating, ventilation, and air conditioning) noise and vibration. Equipment operation (e.g., pumps) and air movement through ducts (aerodynamic noise) cause significant noise if not constructed properly. Air turbulence is the cause of high vibration levels at low frequencies (59 dB @ 31.5 Hz) in air ducts (lined plenum). The problem disappears by installing silencers, changing the duct size (made smaller), and reducing the air duct velocity. Adding acoustical tiles to the walls and acoustical transparent curtains help to mitigate the effect of the reflective electron microscope suite doors. Fan deficiencies (static pressure, airflow, and fan speed) should also be addressed. Most advanced technology buildings place as much mechanical equipment as possible outside the building. These include cooling towers, exhaust fans, scrubbers, and pumps. What is known for certain is that conventional noise control solutions don't necessarily work for advanced technology buildings [36].

1.3.3 Advanced Facilities That Support Nano and Biotech

National Institute of Standards Advanced Measurement Laboratory. The NIST has recently opened the doors to the most advanced measurement laboratory in the world—the NIST Advanced Measurement Laboratory. According to NSET (National Science and Technology Council, Executive Office of the President) in 2004

> NIST has recently constructed the most technologically advanced facilities in the world, the Advanced Measurement Laboratory, which will support industry in the conduct of this research with new ways to more accurately measure, quantify and calibrate important processes and properties.

The NIST's AML, costing $235 million to construct, is a 49,843 m^2 (536,507 sq. ft) facility that is composed of five separate wings, two of which are buried 12 m (39 ft) underground [37,38]. The facility, under the auspices of the Department of Commerce, will provide

> …sophisticated measurements and standards needed by U.S. industry and the scientific community for key 21st century technologies such as nanotechnology, semiconductors, biotechnology, advanced materials, quantum computing and advanced manufacturing. NIST research efforts planned for the new facility range from improved calibrations and measurement of fundamental quantities such as mass, length and electrical resistance to the development of quantum computing technology, nanoscale measurement tools, integrated micro-chip-level technologies for measuring individual biological molecules, and experiments in nanoscale chemistry.

The minimum standard criteria for air quality, temperature control, vibration, and humidity control are cutting edge (**Fig. 1.1**). Air quality is controlled to 3.5 particles per liter (100 particles per cu. ft) as compared to 3,500 particles per liter (100,000 particles per cu. ft) in most modern labs. In standard cu. ft. terms, this converts to 100 particles per cu. ft. Temperature is controlled from ±0.1 to 0.01°C as compared to ±2°C in most labs [37].

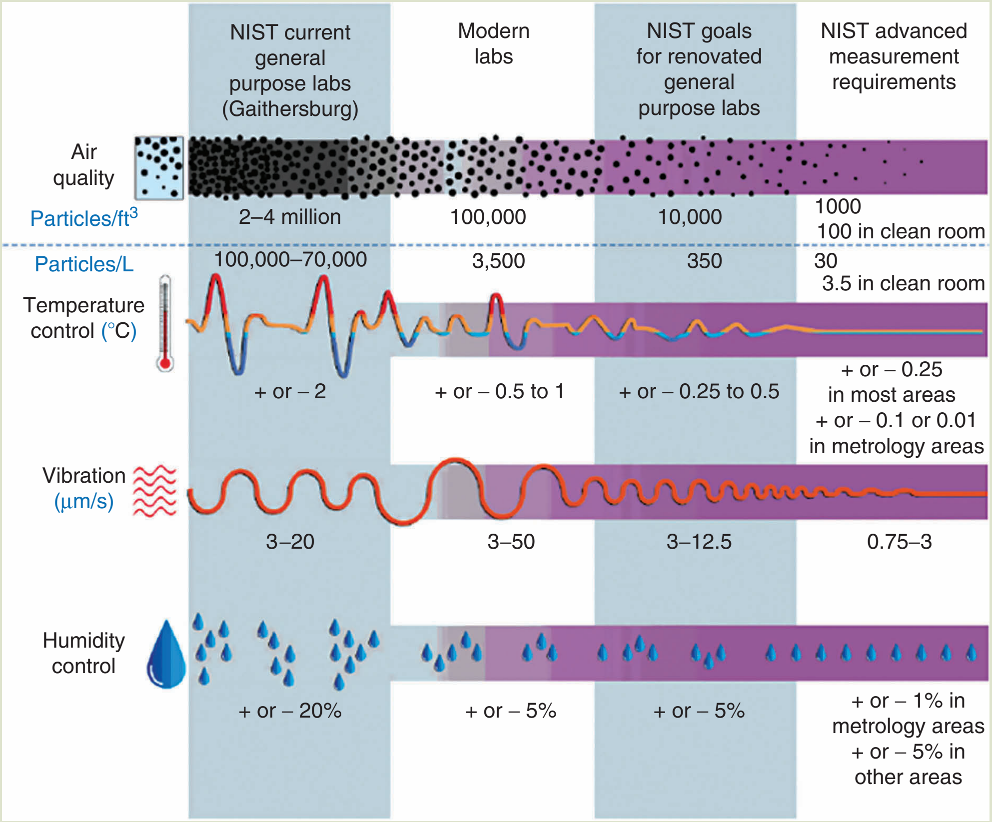
The NIST's AML consists of five interconnected units. The five buildings are united with above ground walkways and underground tunnels. The AML is environmentally stable with regard to humidity, temperature, vibration, electromagnetic interference, and contamination. Metrology activities are conducted in two underground facilities.

There are two single-floor analytical characterization laboratories (housing 187 laboratory modules). Most of the analytical labs are controlled to 20 ± 0.25°C, a few to ±0.1°C. Two underground metrology laboratories (housing 151 laboratory modules) are located 9 m (40 ft) below ground level. There are two types of labs: "quiet" metrology labs are dedicated to measurement, and "rotating or dynamic" labs involve some kind of moving equipment. Selected labs are isolated on concrete slabs (equipped with air springs that are able to cancel out even the slightest of vibrations) to reduce any level of vibration. A multi-floor nanofabrication facility serves as an ultra-clean room.

The Nanofab building has a 18,000 sq. ft "raised-floor" *Class 100* clean room—adaptable for upgrade to *Class 10* if required. A sub-fabrication area is located beneath the clean room, and an interstitial space separates the clean room floor from the mechanical suite. NIST has invested in a completely new set of equipment dedicated to producing 150 MM wafers. The equipment includes furnaces, LPCVD (liquid phase chemical vapor deposition), rapid thermal annealers, three reactive

FIG. 1.1

The level of environmental control in NIST's new AML is compared to other laboratory facilities. The NIST facility has 338 reconfigurable modules. A 8.520 m^2 (91,700 sq. ft) nanofab facility Class 100 clean room *is rated at <3.5 particles·L^{-1}.* Enhanced air quality *is achieved with HEPA (high efficiency particulate air) filters for general-purpose laboratories. Most laboratories have baseline temperature control within ±0.25°C and 48 laboratories have control to within ±0.1 or ±0.01°C.* Vibration *isolation is achieved to a level of 3 μm·s^{-1} or less and down to 0.5 μm·s^{-1} in 27 low-vibration modules.* Humidity control *is held at ±5% relative down to ±1% in special laboratory sections.* Electrical power filtering *provides institute-wide uninterruptible power and counter measures of voltage spikes, drop-outs and other dirty power problems that limit accuracy and precision, reduce analytical sensitivity and cause long-running experiments to crash.* Green building *features include natural daylighting, energy conservation, and recycling.*



Source: Image courtesy of HDR, Inc. With permission.

ion etchers (RIEs), three metal deposition tools (thermal evaporator, electron beam evaporator and ion sputterer), contact lithography capability, electron beam lithography and focused ion-beam lithography. Field emission SEM, spectroscopic ellipsometers, contact profilometers, microscopes, and image capture instrumentation support product and research monitoring and metrology.

A selection of incredible images acquired at AML are displayed in **Figure 1.2**.

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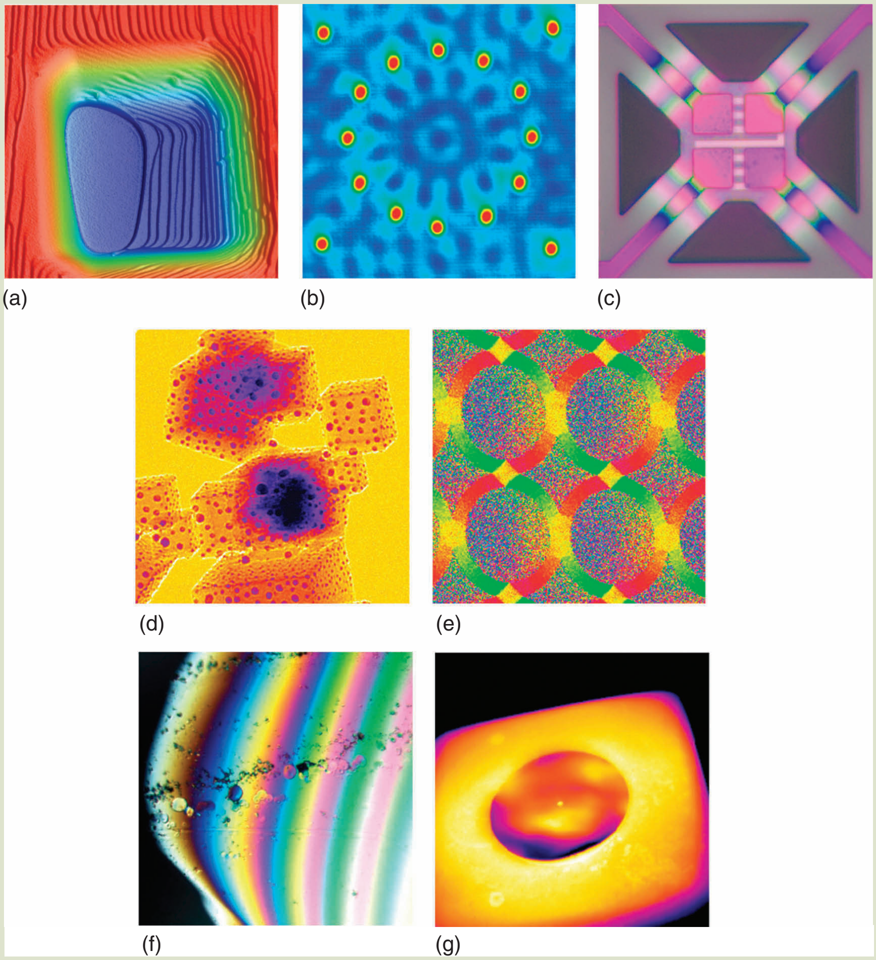
FIG. 1.2

(a) Silicon step rulers that range in height from 10s to 100s of nanometers to a single monolayer measuring 0.3 nm. The microscope used to make the image sits on an isolated concrete slab equipped with air springs to cancel the smallest vibrations. (Image courtesy of J. Fu, NIST.) (b) 12 cobalt atoms in a circle on copper. The interference of electron waves produces a daisy pattern. An instrument autonomously picks up and places the atoms. (Image courtesy of J. Strocio and R. Celotta, NIST.) (c) A microheater is used to detect toxic gases. Variations in the thickness cause changes in color. NIST's ALM facility will produce arrays of these sensors. (Image courtesy of NIST.) (d) MgO cubes decorated with gold nanoparticles are imaged by a new 3-D chemical imaging method using a scanning TEM, a tilting stage, and sensitive detectors. (Image courtesy of J. Bonevich and, J.H. Scott, NIST.) (e) Magnetic domains of new generation logic devices are depicted. Changes in color correspond to changes in the direction of the magnetic field. This image was taken 12 m underground by the highest resolution magnetic imaging instrument in the United States. (Image courtesy of J. Unguris, NIST.) (f) Interference colors indicate the thickness of a clear organic film. Deep blue-brown indicates ~1 μm thickness that corresponds to the thickness required to embed a particle for analysis. The work was accomplished in NIST's ultraclean room. (Image courtesy of C. Zeissler, NIST.) (g) An infrared image illustrates temperature variations as a round swipe cloth is heated to detect the presence of explosives. Dark areas correspond to 40°C. Lightest areas are around 200°C. (Image courtesy of G. Gillen, NIST.)



Center for Integrated Nanotechnologies (CINT). The CINT (also designed by HDR Architecture, Inc.) is located in Albuquerque, New Mexico and was constructed in 2006.

> The vision of CINT is to become a world leader in nanoscale science by developing the scientific principles that govern the design, performance, and integration of nanoscale materials.

CINT emphasis is to take scientific discovery and the integration of nanostructures into the micro- and macroscopic worlds.

CINT's core facility is a $9.8 million 35,600 sq. ft gateway located near two national laboratories: Sandia and Los Alamos. CINT is called a gateway facility because it is able to link two national laboratories with collaborative users from universities and industry. Nanophotonics, nanoelectronics, complex nanomaterials, nanomechanics, and nanoscale bio-micro interfaces are some of the divisions within the CINT facility. From the description of the focus areas given above, one can conclude that integration is indeed a prime directive at CINT—and revisiting the challenges defined earlier in this chapter, attempts to accommodate energy across multiple length scales, combination of top-down and bottom-up fabrication strategies, and interfacing biological and synthetic systems was certainly accomplished in good faith.

CINT has allocated 20,000 sq. ft for office suites, visitor accommodations, computer bays, and communication links. The synthesis wing consists of 15,000 sq. ft and houses chemical benches, hoods, equipment, and bench-top characterization tools. A 12,000 sq. ft integration wing possesses a *Class 100* clean room equipped with flexible fabrication. The characterization wing is a vibration-isolated 15,000 sq. ft facility that houses scanning probe microscopes, nanomechanics tools, laser optics, and microelectronics. Utilities, storage, and service space account for 20,000 sq. ft of the total space. The CINT overall is over 90,000 sq. ft.

Purdue's Birck Nanotechnology Center. We shall present one more facility, the recently constructed Birck Nanotechnology Center at Purdue University (by HDR Architecture, Inc.). The facility cost $45 million to build. It is 220,000 sq. ft and contains Class 10, 100, and 1000 clean rooms. There are over 100 labs and modules and nearly 100 faculty from 24 schools or departments participate in research at the facility.

1.4 National and International Infrastructure

We have reviewed business development, education, careers, and buildings. One more cog in this mechanism that requires introduction is a topic about how all these buildings (and people) are organized. Nanotechnology has brought about, more than ever before, the need for cooperation between and among academia, industry, and government, and between and among nations of our world. In the next few paragraphs, we review a few organizations and infrastructure that support advanced technology research, development, and societal implication awareness.

The logical step in the hierarchy is to create an infrastructure of user facilities (buildings, equipment, and instrumentation). There are several statewide and few nationally recognized infrastructure networks dedicated to nanoscience research and development. The new generation facilities in general support a collaborative environment and incorporates sustainable design solutions with flexible, modular designs.

1.4.1 Research and Development Organizations

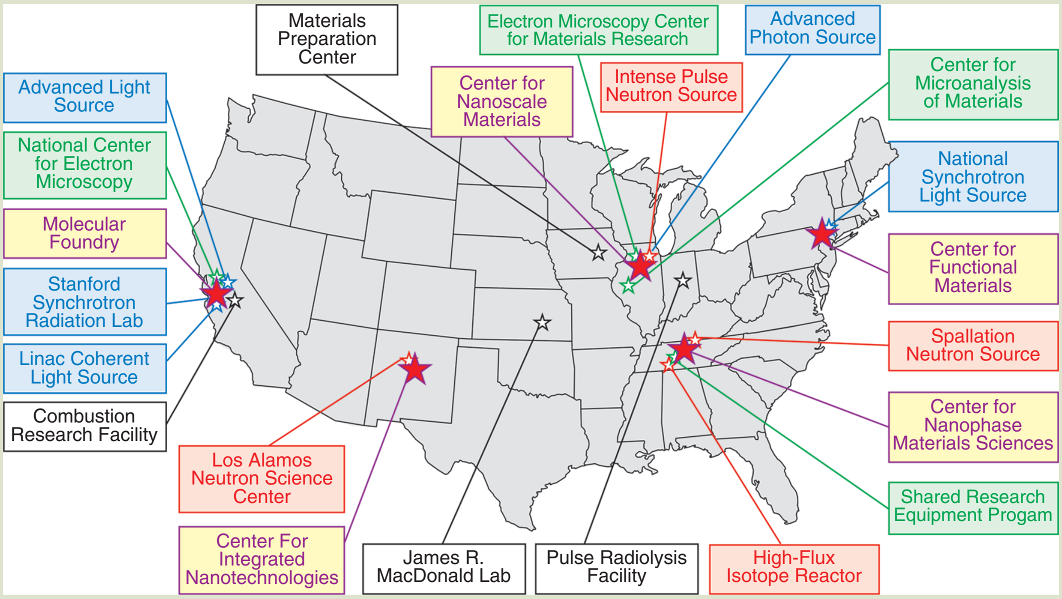
The National Nanotechnology Infrastructure Network (NNIN). The NSF released a solicitation in 2003 to invite universities to submit proposals for membership in the NNIN. On March 1, 2004, the NNIN was officially launched. The NNIN is an integrated partnership of 13 user facilities that is dedicated to support nanoscale fabrication, synthesis, characterization, modeling, design, computation, and hands-on training [39]. The NNIN supports academia, small and large industry, and government in the capacity of a research facilitator with open access by providing leading edge tools, instrumentation, and expertise.

The member institutions include Cornell Nanoscale Facility, Stanford Nanofabrication Facility, University of Michigan Solid State Electronics Laboratory, Georgia Institute of Technology Microelectronics Research Center, University of Washington Center for Nanotechnology, Penn State Nanofabrication Facility, Nanotech at the University of California at Santa Barbara, the Minnesota Nanotechnology Cluster (MINTEC), Nanoscience at the University of New Mexico, the Microelectronics Research Center at the University of Texas, the Center for Imaging and Mesoscale Structures at Harvard, the Howard Nanoscale Science and Engineering Facility, and the Triangle National Lithography Center at North Carolina State University [40].

The NNIN, according to its Web site, "provides unparalleled opportunities for nanoscience and nanotechnology research." The NNIN provides extensive support in nanoscale fabrication, synthesis, characterization, modeling, design, computation, and hands-on training [39]. The NNIN embraces and promotes educational programs to inform the public, educate K-12 students, employ and train undergraduates, develop curriculum, develop technological workforce, train teachers, and numerous other programs and objectives.

The Department of Energy's National Science Research Centers (NSRC). The U.S. Department of Energy (DOE) has five centers for nanoscience (**Fig. 1.3**). (1) the *Molecular Foundry* (Lawrence Livermore National Laboratory) is involved in advanced light sources, electron microscopy, and the "nanowriter"; (2) advanced proton source, intense pulsed neutron source, and an electron microscope center for materials research are found at the *Center for Nanoscale Materials* (Argonne National Laboratory); (3) there is the *Center for Functional Nanomaterials* at Brookhaven National Laboratory; (4) the *Center for Nanophasic Materials* Sciences (Oak Ridge National Laboratory); and (5) Los Alamos and Sandia's Center for Integrated Nanotechnologies is involved with semiconductor research,

Fig. 1.3 *The Department of Energy's Nanoscale Science Research Centers (NSRCs) are depicted. The National Renewable Energy Laboratory (NREL) in Golden, Colorado also accomplishes a significant amount of work at the nanoscale.*



microelectronics, combustion research, and magnetic field laboratories. All of these facilities, and those of the NIST and other facilities in Europe and Asia, are concerned with integrating science and engineering across all scientific disciplines and across all size scales [28].

DOE's investment in nanotechnology is expected to exceed $500 million from 2007 to the present [40]. The Molecular Foundry, located near U.C. Berkeley, is a new center of high-powered nanotech R&D. The center contains clean room facilities, high-powered computing capability, highly sensitive equipment and instrumentation, and top-notch researchers [40].

1.4.2 Economic Development Organizations

The NanoBusiness Alliance (NBA). The NanoBusiness Alliance (www.nanobusiness.org), known as the "world's leading nanotechnology trade organization" made the national scene in nanotechnology business ca. 2002. The organization was founded by Mark Modzelewski and others who realized that nanotechnology was fast coming of age. The current executive director is Sean Murdock who recently testified before the House Science Committee in April 2008 in support of the National Nanotechnology Initiative Amendments Act of 2008.

1.4.3 Organizations Centered on Societal Implications

National Nanotechnology Initiative. The NNI (at www.nano.gov) was established in 2001. Mihail C. Roco is its executive director. The goals of the NNI are quite comprehensive and far-reaching:

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- Advance a world-class nanotechnology research and development program
- Foster the transfer of new technologies into products for commercial and public benefit
- Develop and sustain educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology
- Support responsible development of nanotechnology

Although the NNI is involved in many other areas (e.g., the NNIN and other programs), its efforts have spearheaded recognition of the importance of societal implications of nanotechnology. A number of excellent resources are available from the NNI Web site. Please consult this Web site often and in detail. Intergovernmental agency and department efforts are under the auspices of the National Nanotechnology Coordination Office (NNCO).

Center for Responsible Nanotechnology (CRN) [41]. The Center for Responsible Nanotechnology is a nonprofit research and advocacy group that is focused on the major societal and environmental implications of nanotechnology. The group was formed in 2002 by Mike Treder and Chris Phoenix. They also stress the development, evaluation, and implications of molecular manufacturing (e.g., fourth generation nanotechnology). Their mission statement reads as follows.

> The mission of CRN is to: 1) raise awareness of the benefits, the dangers, and the possibilities for responsible use of advanced nanotechnology; 2) expedite a thorough examination of the environmental, humanitarian, economic, military, political, social, medical, and ethical implications of molecular manufacturing; and 3) assist in the creation and implementation of wise, comprehensive, and balanced plans for responsible worldwide use of this transformative technology.

Foresight Institute. The mission of the Foresight Institute is to "ensure the beneficial development of nanotechnology." The foresight institute is essentially a think tank and public interest institute, this according to their Web site at www.foresight.org. The group was founded in 1986 and lists as the foremost challenges (with solutions through nanotechnology):

- Providing renewable clean energy
- Supplying clean water globally
- Improving health and longevity
- Healing and preserving the environment (and maximizing productivity of agriculture)
- Making information technology available to all
- Enabling space development

In January of 2008, the Foresight Institute released a roadmap for nanotechnology development [42,43].

1.4.4 Nanotechnology News Services

A great way to keep abreast of nanotech news is to subscribe to a variety of free news services. Several notable services are listed below.

- Nanoscienceworks Newsletter (www.nanoscienceworks.org)
- Nanotechnology Now (www.nanotech-now.com)
- Nanotechweb.org, IOP Publishing (www.nanotechweb.org)
- Nature Nanotechnology (www.nature.com/nano/index.html)
- Nano Vip Newsletter (www.nanovip.com/nanotechnology-newsletter)
- Nanotechnology.com, the international small technology network (www.nanotechnology.com)
- Small Times Magazine (www.smalltimes.com and www.nanotechnews.com)
- Nanowerk Nanotechnology News (www.nanowerk.com)
- The A to Z of Nanotechnology (www.azonano.com)
- Nanodot (www.foresight.org/nanodot/)
- Nanotechnology News Network (www.nanonewsnet.com)
- Chemical & Engineering News (www.pubs.acs.org/nanofocus/)
- Nano Techwire (www.nanotechwire.com)
- Nano World News (www.nsti.org/news/)

The list keeps on growing and growing.

For business, the Forbes/Wolfe Nanotech Reports (www.newsletters.forbes.com), Scott Livingston's Axiom Capital Management (www.axiomcapital.com), and Lux Capital (www.luxcapital.com) should keep you updated about the investment aspects of nanotechnology.

1.4.5 International Organizations and Institutes

There are numerous organizations overseas. Europe has several that are involved in every aspect of nanotechnology. The list is by no means complete. Please find out what is going on in your world.

North America

- Nanotechnology—National Research Council Canada (www.nrc-cnrc.gc.ca)
- NRC National Institute for Nanotechnology (www.nint-innt.nrc.gc.ca)
- National Institute for Nanotechnology—University of Alberta (www.uofaweb.ualberta.ca/nint)
- Canadian NanoBusiness Alliance (www.nanobusiness.ca)

Europe

- Nanoforum.org: European Nanotechnology Gateway (www.nanoforum.org)
- Nanotechnology (cordis.europa.eu/nanotechnology)
- ENTA—European Nano Trade Alliance (www.euronanotrade.com)
- Institute of Nanotechnology (www.nano.org.uk)
- Swiss Federal Institute of Technology (Ecole Polytechnique Fédérale Lausanne, EPFL) (www.epfl.ch)

Asia

- Asian Institute of Technology (www.ait.ac.th)
- National Nanotechnology Center (NANOTEC) (www.asia-nano.org)
- Asia Nano Forum (www.asia-nano.org)

- The Australian Research Council Nanotechnology Network (www.ausnano.org)
- Nanotechnology Research Institute (NRI) (unit.aist.go.jp/nanotech)
- Nanotechnology India (www.indiannanotechnology.com)

Africa

- South African Nanotechnology Initiative (SANi) (www.sani.org)
- Focus Nanotechnology Africa, Inc. (www.fonai.org)

South and Central America

- Laboratorio Nacional de Nanotecnologia (LANOTEC) in Costa Rica (www.cenat.ac.cr/cenat)
- Brazilian Nanotechnology Networks
- Development of Nanoscience and Nanotechnology (Brazil)
- Nanoscience Millennium Institutes (Brazil)
- Fundacion Argentina de Nanotecnologia (FAN) (www.fan.org.ar)

1.5 Nanotechnology Products

Fundamentals of Nanotechnology is about applications of nanoscience to commerce and industry. In other words, nanotechnology is about development and manufacturing of products enhanced by the remarkable properties of nanomaterials. We therefore present, to conclude the perspectives aspect of this text, a list of some products that you may or may not be aware that are associated with nanotechnology. Most of the products were found on the NNI's Web site, www.nano.gov. In addition, please consult www.nanotechproject.org/ for an extensive list of hundreds of products that have been enhanced with nanotechnology.

Automotive Industry

- Step assists, bumpers, paints, coatings, glare reduction, catalytic converters
- Cooling chips to replace compressors with no moving parts

Recreation

- Lighter stronger tennis racquets, long-lasting tennis balls, smart golf balls
- Nanotube reinforced masts for sailboats, new materials for hull and deck
- Golf shafts, skis, fog eliminators

Personal Use and Food

- Sunscreens, cosmetics, stain-free clothing
- Silver nanoparticle food storage containers, cutting boards, pans
- Nonstick bake ware
- Umbrella (based on lotus leaf)

Medicine, Therapeutics, and Hygiene

- Dental-bonding agents, burn and wound dressings
- Medical imaging with quantum dots
- Targeted drug delivery and gene therapy

- Water filters
- Lab-on-a-chip diagnosis
- Sanitized toilets

Structural Materials and Industrial Applications

- Stronger, lighter polymers; enhanced concrete, enhanced steel
- Wear-resistant nanoceramic coatings
- Catalysts
- Carbon nanotube-reinforced materials
- Various nano glues, nanoseal wood, nano-enhanced insulation
- Self-cleaning glass
- Exterior paint

Electronics and Computing

- Sub-100 nm transistors (old technology)
- Carbon nanotube triodes
- Organic LEDs and organic electroluminescent displays
- Cordless power tool batteries
- Carbon nanotube displays
- Protective self-assembling film layers for displays
- Cellular memory

Satisfy your own curiosity and research the amazing number of products out there that have already been enabled or enhanced with nanotechnology.

Acknowledgments

We would like to acknowledge Michael Burke, CEO & President of NanoThread, Inc. for his contribution to section 1.1. We are also indebted to the NNI for their central focused efforts to keep the United States abreast in the quest to commercialize nano.

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Problems

1.1 What is the combined decibel level if you are talking in a restaurant at 70 dB and the adjacent noise from the kitchen contributes another 70 dB?

1.2 With regard to vibrations—acceleration, velocity, and displacement are all related by simple equations. How so?

1.3 Vibrations that influence equipment range from 1 to 100 Hz. Give examples of sources of 1-, 25-, 50-, and 100-Hz vibrations.

1.4 Clean rooms of Class 100 indicate that there are no more than 100 0.5-µm particles per cubic foot. What applications would require such tight control and why?

1.5 What products can you think of that cannot be enabled or enhanced by nanotechnology?

1.6 a. If someone is exposed to sound intensity of 1×10^{-12} $W \cdot m^{-2}$, how does this translate into decibels? b. What is the intensity of sound in terms of $W \cdot m^{-2}$ of jet plane noise at takeoff if the recorded decibel level is 140?

1.7 What is your vision of a building (research center) of the future?

1.8 List all potential employers that involve nanotechnology but are not involved in science, technology, or manufacturing—for example, an intellectual property attorney.

1.9 List three reasons why it is not a good idea to place a TEM room next to a loading dock. (Hint: There is one subtle reason you might miss).
1.10 Is nanotechnology an industrial revolution in the making?
1.11 When starting a nano-based business, discuss the importance of partnerships.
1.12 Research the economic cluster model in Arizona. What do you think?
1.13 Do you agree that government should be heavily involved in funding nanotech? Why or why not?

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